BONE-GRAFTING

IN THE

TREATMENT OF FRACTURES

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FOREWORD

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PREFACE

THE work of Albee and the other great masters of bone grafting needs no acknowledgement by me The value of their teachings and example in the development of this branch of Orthopaedic Surgery cannot be over estimated

Unhappily the times in which we live have greatly increased the demands on reparative surgery of the locomotor system This has led not so much to the discovery of any new or revolutionary principles of treatment as to an increased awareness of the vital importance of attention to the many details which can make or mar the final result

The value and scope of bone grafting in the treatment of fractures are obvious In the practice of this particular branch of orthopaedic surgery one is inevitably confronted by many problems and practical difficulties On turning to the standard text books I have been disappointed again and again by the lack of space allotted to the application of bone grafting to the treatment of fractures Descriptions of operative technique are curtailed information regarding pre and post-operative treatment is scanty and many of the procedures described are of historic interest only

Diagrammatic representations of fine examples of the joiner's art and radiographs showing spectacularly convincing results are poor consolation to a surgeon with a practical problem to solve This book has arisen out of the difficulties I have encountered and my aim has been to make it as simple and as practical as possible

Arthodesis has been discussed only in connection with certain fractures of the tarsus and spine in which I believe it to be the best initial treatment and I have quite frankly avoided any detailed discussion of the vexed question of the place of bone-grafting in the treatment of fractures of the neck of the femur

Most of the radiographs and the statistics included in the Appendix were taken from the records of one of the Royal Air Force Orthopaedic Centres and I am indebted to the Director General

of the Royal Air Force Medical Service, Air Marshal Sir Harold Whittingham, for permission to use this material. Mr Watson-Jones has been kind enough to write a Foreword, and it is a pleasure to record the great debt which I, in common with all the other Orthopædic surgeons in the Royal Air Force, owe to him and to Air Commodore Osmond Clarke for their never-failing assistance, encouragement, and advice. The colour photographs were taken by Mr Hennell, whose services were made available through the Medical Research Council by the Directors of the Metal Box Company Mr Hennell's colour photography has already set a new standard in the illustrating of medical text-books.

I have had much valuable assistance and advice from Mr Charles Macmillan of Messrs Livingstone; his patience and enthusiasm were a revelation to a completely inexperienced author Finally I must pay tribute to every single member of the Orthopædic "team" in the centre to which I am attached Without the stimulus of their keenness and pride in their work this book would probably never have been written

J R ARMSTRONG

ELY,
December 1944.

FOREWORD

THE principles of bone grafting were known to John Hunter two hundred years ago His study of the rich vascular bed of the antlers of the deer grown with such lavish expenditure year by year taught him the importance of blood supply in the formation of bone He knew that in the healing of fractures bone was formed by the growth of a vascular cellular tissue from surrounding muscles and periosteum and from the bone ends themselves He knew that in this process of repair it was possible for bone fragments completely stripped of all soft tissue attachments to be incorporated in the mass of newly formed bone and even to contribute towards union by bridging the fracture By implanting a human tooth in the comb of a cock he proved that transplanted tissues could survive long enough to await revascularisation He even transplanted the bone spurs of hen chickens into the legs of young cockerels and saw them take root and grow But Hunter did not establish bone grafting as part of surgical technique He was defeated by sepsis The time was not yet ripe for the full development of his brilliant programme

Seventy years after John Hunter's death Lister published his work on the control of wound infection and a few years later in the same building in Glasgow where Lister developed his technique another young surgeon wrote a new chapter in surgical history It was William Macewen who at the age of twenty nine had already introduced the operation of wedge osteotomy for the correction of rachitic deformity A boy was brought to hospital for amputation of the arm the humerus had been resected for osteomyelitis regeneration had failed and the limb was flail and useless Macewen was unwilling to amputate and he decided to make use of fragments of osteotomised bone from other patients Bone wedges were gathered from the legs of six bow legged boys and transplanted to become intrinsic parts of the humerus of a seventh The operation was successful The reconstructed bone measured six inches in length

four inches of it consisting of transplanted bone The patient grew to be a capable workman with a strong though slightly curved humerus eleven inches long

Bone-grafting was thus introduced in 1880 in the wards of the Royal Infirmary, Glasgow But the modern technique of bone-grafting received no less powerful an impetus in 1894 from the wards of Guy's Hospital, London Arbuthnot Lane resolved "to treat the bones as one would the broken leg of a table or chair " He established the principle of internal fixation and set a new standard in the treatment of fractures His methods of operative reduction were guided by rules of precision, and internal fixation was achieved by metal plates and screws With similar purpose Fred Albee of New York devised "a surgical armamentarium for cutting and modelling bone which at least approaches that of the power-driven precision tools of the machinist or cabinet maker " Surgeons began to learn from other craftsmen In recent years they have acknowledged one more debt, this time to the metallurgist, for stainless steel, vitallium and other alloys have made it possible to use screws without fear of reaction or loosening in the bone The ideal device of the future may not be an alloy of metals—it may be an absorbable plastic But meanwhile surgeons no longer fix bones to each other by the methods of the amateur—the twisted bits of wire and the fragments of catgut which any carpenter would laugh to scorn They use nails, flanged nails and screws, they achieve reliable and lasting fixation, they have developed the modern technique of onlay bone-grafting

In his monograph on bone-grafting in the treatment of fractures Mr Armstrong's work reflects the surgical development of two hundred years—the research of Hunter, the work of Lister, the inspiration of Macewen, the skill of Lane and the craftsmanship of Albee On this very sure foundation, linked to recent research in metallurgy, is based a technique of bone-grafting which almost completely solves the problem of slow union delayed union and non-union Mr Armstrong has dealt faithfully with every detail of technique that the young surgeon must know. He has the advantage of being young himself—the age when many surgeons of the past have made their greatest contribution He is a leading member of the team of orthopædic surgeons of which the Royal Air Force is proud, surgeons who have shouldered heavy responsibility, gained vast experience and treated the fractures of pilots and aircrews

which are characterised by astonishing severity and multiplicity. In all their work the highest possible standard has been set. It has been maintained by the vigilance of Osmond Clarke who as Service consultant is also young in outlook but is nevertheless mature in judgment. But it has been achieved without standardisation or suppression of initiative. Central dictation of technique is the easy method of assuring a uniformly high standard but from the point of view of surgical progress it is the pernicious method. And thus will be found in the work of Armstrong in the technique of sub astragaloid arthrodesis the practice of bone-grafting the scaphoid and in other operations the provocative stimulating approach of the individual.

A warning is necessary. The technique of onlay bone grafting with vitallium screw fixation is well established. Brilliant results can be achieved, deformity can be prevented, union can be accelerated, non union can be avoided. But let it be remembered that John Hunter was defeated by sepsis. Let it be remembered that internal fixation was no more than part of the contribution made by Arbuthnot Lane; no touch technique was the other part. Even to-day the general standard of asepsis in operative technique is far too low. To infect a closed fracture is a disaster of the first magnitude; it is no less worthy of a court of inquiry than a railway disaster. The surgeon who proposes to adopt the recommendations of this monograph must first achieve so perfect a command of aseptic technique that if within a few days of operation the patient develops a febrile reaction he can say with complete confidence: He may have pleurisy, he may have pneumonia, but whatever he has I am quite certain that he has no infection of the wound.

R. Watson-Jones

20th November 1941

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CHAPTER I

PRINCIPLES, GENERAL INDICATIONS, CONTRA-INDICATIONS

PRINCIPLES

THE autogenous bone graft has two functions, being both an internal splint and a scaffolding by or from which new bone is formed. Bone-grafting properly carried out is a valuable measure in the treatment of a wide range of fractures and in certain circumstances is the only effective treatment. It is not sufficient, however, simply to place a graft of indeterminate size across a fracture, so that it is more or less in contact with the host bone, and then immobilise the limb. To produce really satisfactory results certain basic conditions must be fulfilled.

1. *There should be close and stable contact between large areas of raw bone on the graft and host.*—It is unlikely that an autogenous bone graft lives and "takes" in the way that a free epithelial graft "takes" on a granulating surface. More probably it dies and is replaced by living bone by a process of creeping substitution. In either event revascularisation is the essential process whereby the graft becomes living bone. The host bone is the source of this revascularisation: capillary vessels grow from it and spread throughout the graft. Several factors influence this growth. The graft should be in contact with a vascular area: the deeper layers of the cortex and the medullary cavity are a much more effective source of capillary growth than the hard superficial cortex. Similarly, the graft will be more easily revascularised if it consists at least in part of soft cancellous endosteal bone into which capillaries can grow easily, and this layer of the graft should be in immediate contact with the host. Finally, the larger the areas of graft and host brought into contact, the more rapid will be the revascularisation of the graft and its subsequent replacement by living bone.

2. *Fixation of the graft and fracture must be mechanically stable.*—Any movement at all between graft and host tears the fine capillaries and delays or prevents revascularisation. In the same way, movement between the fractured surfaces delays union by traumatising

the delicate tissues which are the framework of repair. External fixation reduces to a minimum the mechanical strains and stresses to which the graft and fracture are exposed, but absolute immobilisation can be ensured only by a combination of external and internal fixation.

To produce adequate internal fixation the graft must be strong enough to withstand the forces to which it may be subjected, without bending or breaking. It must, therefore, be large and consist in part of hard cortical bone Soft cancellous bone, while of a high osteogenic value, is not strong enough to form an efficient internal splint Fixation between the graft and the fragments of the host above and below the fracture must be mechanically efficient and must remain stable until consolidation is complete.

Provided fixation is effective the use of cancellous bone or bone chips packed around the fracture is logical. Under these circumstances such fragments are not subjected to any strains and act as a supplementary source of new bone

3. *Before grafting the fractured surfaces should be cleared of fibrous tissue and sclerotic bone* —If allowed to persist, these form a barrier to the process of repair

4. *Normal apposition and alignment of the fragments of the host bone should be restored* —Accurate apposition of the fractured surfaces reduces to a minimum the new bone formation necessary to effect union. If actual bone loss has occurred the gap should be filled with cancellous bone after it has been bridged by a stout graft. Mal-alignment, if uncorrected, causes dysfunction and disturbs the mechanical efficiency of the joints above and below the fracture.

5. *The architecture of the reconstructed bone as a whole should as far as possible approximate to normal at the conclusion of operation* — This reduces to a minimum the amount of bone absorption and new bone formation necessary in the process of repair

GENERAL INDICATIONS FOR BONE-GRAFTING

The decision to treat a fracture by operative rather than conservative methods should never be made lightly Serious though the failure of conservative treatment may be, an unsuccessful operation may well result in tragedy This applies particularly to bone-grafting, which is always a formidable procedure. In certain

Fig 1
Established non union Fracture surfaces sealed off by a layer of avascular sclerotic bone

Fig 2

Fig 3

Fig 4

Figs 2 and 3.—Delayed union A nine-months-old fracture showing fibrous union only with early sclerosis of the bone-ends.

Fig 4 shows the same fracture two weeks after the initial reduction The distraction present accounts for the subsequent delay in union.

types and conditions of fracture, however, conservative methods alone are not enough When operation is necessary bone-grafting may be definitely indicated, or may simply be one of several alternative procedures which might be employed successfully

Established non-union.—An un-united fracture in which the bone-ends have become sealed off by an avascular sclerotic layer will not unite, however long it may be immobilised (Fig. 1). Such operative measures as drilling or "freshening" of the bone-ends are not always followed by union, and adequate bone-grafting is by far the most effective procedure

Delayed union.—There are wide individual variations in the period of immobilisation necessary to allow bony union in any particular fracture. Such factors as infection, a poor blood supply, repeated manipulations, distraction, or inadequate immobilisation may, however, cause union to be delayed far beyond the normal limits (Figs. 2, 3, and 4) At this stage the fractured surfaces are joined by soft fibrous tissue containing little callus, the bone-ends are relatively avascular and are beginning to "round off," and atrophic decalcification is evident elsewhere throughout the limb. If adequate immobilisation is continued and combined with the maximum possible functional activity of the limb most of these fractures will ultimately unite. In suitable cases, however, the period of treatment can be substantially reduced and ultimate union ensured by timely bone-grafting.

Bone loss.—A high-velocity missile, a too enthusiastic debridement, or infection and subsequent sequestration can result in considerable loss of bone in a compound comminuted fracture This may be of an extent sufficient to delay unduly or even to prevent union. When all infection has subsided the actual loss of bone can be made good and union accelerated by bone-grafting (Figs 5, 6, and 7)

After osteotomy.—Occasionally a fracture is allowed to unite in malposition sufficient to cause material disability, which can only be relieved by an osteotomy and correction of the displacement at the site of fracture (Fig. 8) This should be done, provided the malposition has not been of sufficiently long standing to cause permanent secondary changes in the joints above and below the fracture. Bony union after an osteotomy through the site of a recent fracture is often delayed and, if osteotomy is followed by bone-grafting, not only is union accelerated but the danger of re-

displacement is minimised by the combination of internal with external fixation

After open reduction —It is not always possible to effect adequate reduction of a fracture without operation (Figs 9 and 10) Inter position of soft tissue or buttonholing of the periosteum may prevent

Fig 5 Fig 6 Fig 7

Fig 5 —Bone loss. A four-months-old fracture due to a gunshot wound Figs 6 and 7 show the same fracture eight weeks and four months after grafting

reduction by manipulation or traction even if these measures are tried immediately after injury Later reduction becomes increas ingly difficult in all fractures and after three or four weeks may be impossible using conservative methods only Moreover repeated manipulations or continued strong traction substantially delay union For these reasons open reduction is often necessary and should always be combined with some form of internal fixation Trans fixion screws, or plates and screws are effective means of fixation

FIG 8

Mal-union A fracture of the tibia and fibula which has been allowed to unite with gross bowing

FIG 9

FIG. 10

FIG. 11

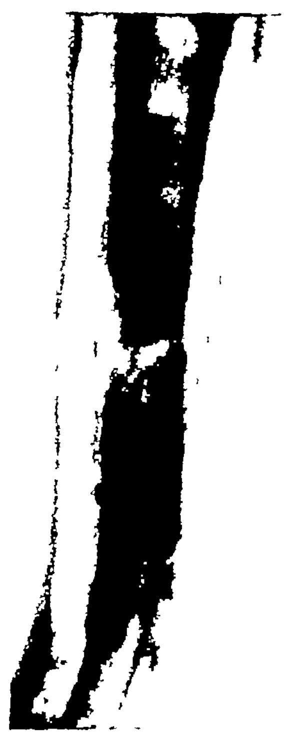

FIG 12

FIGS 9 and 10 —A fracture requiring open reduction. The central fragment had penetrated the periosteum and could not be reduced by manipulation. FIGS 11 and 12 show the same fracture after open reduction and grafting

but beyond their mechanical efficiency do nothing to promote union Indeed it is clear that ionisable metals introduced around a fracture retard union If there is any reason to suspect that union may be delayed a bone-graft is the best means of effecting internal fixation (Figs 11 and 12)

FIG 13 FIG 14 FIG 15 FIG 16

FIGS. 13 14 15 and 16 —An unstable fracture The initial reduction was adequate (13 and 14) but, due to comminution, complete re-displacement had occurred one week later in spite of an adequate plaster (15 and 16)

Unstable fractures —Some fractures are so unstable that reduction cannot be maintained by external fixation alone (Figs 13 14 15 and 16) It may be necessary particularly in oblique fractures with a loose butterfly ' fragment to employ both internal and external fixation if re-displacement is to be avoided This type of fracture often occurs in areas of the shafts of the long bones where because of a poor blood supply union always tends to be slow In these circumstances bone grafting has advantages over other methods of internal fixation

CONTRA-INDICATIONS TO BONE-GRAFTING

Sepsis.—Wound infection after bone-grafting is a major disaster. Loss of the limb or even of life may follow a virulent infection. Involvement of the host bone may produce an osteomyelitis dragging

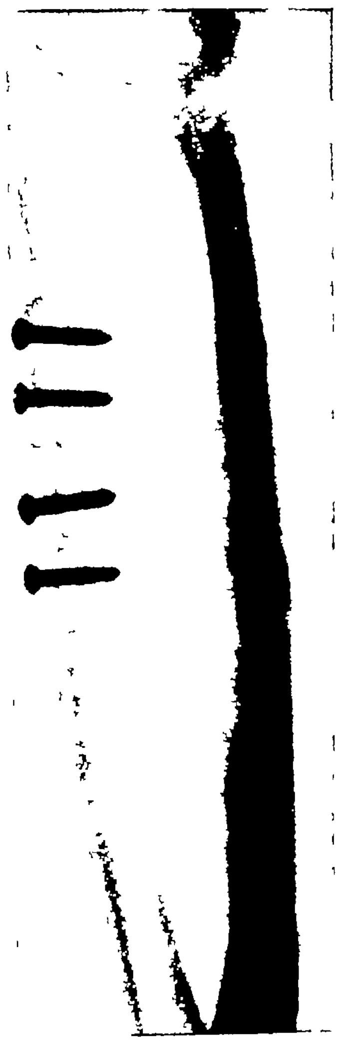

FIG 17

FIG 18

FIGS 17 and 18 —The results of infection A simple fracture of the radius was grafted (17) and became infected Three months later, after the screws, the dead graft, and several loose sequestra had been removed, infection of the bone persists and bone loss due to sequestration has produced a large defect in the radial shaft and a dislocation of the inferior radio-ulnar joint (18) The patient's last state is much worse than his first

on for years. The least serious result which can be expected is sequestration of part or all of the [illegible] with indefinit [illegible] union (Figs. 17 and 18)

Any skin lesion or unheal [illegible] the affect [illegible] r any

active septic focus elsewhere in the body precludes operation An apparently subsided infection around a compound fracture may only be latent and may flare after operation Such fractures must be approached with special care Operation should be undertaken only after the surgeon has satisfied himself on clinical and radiological grounds and by observation of the reaction of the fracture to a test period of increased activity without external support, that infection has indeed resolved Pin tracks in which there is a chronic low grade infection are another commonly overlooked source of infection

It must be emphasised that infection following a bone graft should always be regarded as directly due to an error of judgment in operating in the presence of an undetected infection to an inadequate skin preparation or to bacteria introduced at operation by failure to observe an effective aseptic technique The theory, comforting to the surgeon, that infection is often blood borne is made untenable by the extreme rarity of local infection in closed fractures The results of infection following an operation on bone are so disastrous that it is quite unjustifiable to take any risk whatever if it may be avoided

Inadequate theatre facilities.—If any doubt exists as to the absolute efficacy of the aseptic theatre technique available bone grafting should not be undertaken A few basic instruments are necessary For example it would be extremely difficult to perform a satisfactory bone graft without bone clamps or bone holding forceps and a motor-driven saw and drill An efficient theatre sister trained in orthopædic surgical methods and no-touch technique is an essential Bone-grafting is never an operation of extreme urgency and if the available facilities are considered inadequate it is better to transfer the patient to a fully equipped orthopædic centre

Other existing lesions.—An un united fracture may be associated with other lesions sometimes the result of previous treatment The immobilisation necessary after bone-grafting might have a very injurious effect on such lesions and might even result in their becoming permanent For example delayed union of tibial fractures is not uncommonly associated with a fixed equino-varus deformity of the foot, the result of prolonged immobilisation in this position It is better to correct such a deformity by manipulation and plaster before undertaking bone-grafting If any lesion is present which

is likely to be made worse by immobilisation operation should be deferred until it has been dealt with.

Adherent scars.—An area of complete skin loss associated with a compound fracture may heal leaving an avascular scar closely adhering to underlying bone. Although early epithelial grafting of wounds has reduced the incidence of this complication such scars are not uncommonly associated with a fracture requiring bone-grafting. Operation entailing a stripping of the bone-ends to expose the fracture deprives the scar of its already precarious blood supply. The whole area may subsequently break down, leaving the fracture and graft exposed This is followed by sequestration of part or all of the graft, and union is indefinitely delayed. Before operation is contemplated the co-operation of a plastic surgeon should be sought, to replace the scar with healthy skin by a transferred skin flap Immobilisation of the fracture can be continued in a plaster with a window large enough to afford easy access to the scar, and grafting is deferred until the flap has healed soundly.

CHAPTER II

TYPES, SOURCES, AND FIXATION OF GRAFTS

MANY procedures for bone grafting have been described The grafts used vary in size in composition and in the method by which they are brought into contact with and fixed to the host bone Since these procedures are by no means equally satisfactory good results depend primarily on the selection of the most effective operative technique

Intra-medullary grafts —A closely fitting cortical graft is driven into the medullary cavity of one fragment leaving a portion protruding from the fractured surface This is introduced into the opposite fragment by manipulation and the fracture is impacted The graft then lies across the fracture in the medullary cavity of the host bone This method has many disadvantages The length of graft which can be introduced into the second fragment is limited by the amount of distraction which can be produced by manipulation, and may be too short to effect adequate fixation If the graft is sufficiently loose to permit of its being "threaded" along the medullary cavity so that its centre lies opposite the fracture line it does not grip the fragments firmly enough to prevent considerable movement at the fracture Besides these mechanical disadvantages, the introduction of a hard cortical plug into the medullary cavity seriously diminishes the blood supply to the bone-ends and often produces non union Should union occur the normal medullary cavity can only be restored by complete absorption of the graft, a process which may take years The use of intra medullary grafts should be limited to those rare occasions in which this method is the only practicable procedure

Inlay grafts —The graft is introduced into a slot cut through the cortex of the host bone and across the fracture It is placed so that its various bony layers coincide with those of the host and fits closely into its bed Grafts are usually rectangular cut with a double saw, but may be wedge or diamond shaped Accurate fitting may be sufficient to produce immobilisation, but usually added fixation is

necessary. Loops of catgut or wire, transfixing bone pegs, or screws may be used to fix the graft more firmly in its bed The advocates of inlay grafting point out that this technique restores the structure of the bone to normal, and that three surfaces of the graft are brought into contact with the host. This method has, however, several disadvantages The size of the graft is limited by the size of the slot which it is possible to cut in the host bone, and a fracture of the graft itself is not unknown "Springing" a closely fitting graft into its bed is difficult; grafts have been broken and bones split during this manœuvre At best, fitting is rarely accurate enough to be depended on without added fixation, and the insertion of screws, the only really reliable method of fixation, frequently results in driving the graft into the medullary cavity of the host, where it is less effective. Many so-called inlay grafts are, in fact, intramedullary. The whole technique is somewhat protracted and difficult, and I consider it has no advantages and several disadvantages when compared with the much simpler procedure of onlay grafting.

Onlay grafts.—After the fracture has been reduced the graft bed is prepared by removing with a chisel about one-quarter of the circumference of the fragments for a suitable distance above and below the fracture On the flat surface of raw bone thus produced the graft is laid and held with bone clamps It is then fixed to the host bone by screws driven through the graft and gripping firmly on the opposite cortex (Figs. 19 and 20). The amount of bone which should be removed to prepare the graft bed is important. By completely removing part of the cortex the vascular medullary cavity is brought into direct contact with the deeper layers of the graft On the other hand, fixation is made more secure by preserving a thin layer of cortex, as the screws have then three layers of hard bone on which to grip It is probably best to leave a thin layer of cortex when preparing the graft bed with the chisel, and subsequently open up the medullary cavity by a series of large drill holes through this layer These drill holes are avoided when inserting the screws.

This technique is simple and effective. A massive graft can be used and fixation by screws is mechanically sound. The method is particularly suitable for grafting all types of fracture of the shafts of the long bones.

"Double" onlay grafts.—Double onlay grafts are employed

when the host bone is too fragile to allow stable fixation of a single graft. In some fractures, particularly those associated with bone loss the bone-ends are atrophic decalcified and may even be conical In such circumstances two onlay grafts, placed on opposite surfaces and fixed firmly together with screws, are used The host bone is

FIG 19

FIG 20

FIGS. 19 and 20 —Onlay graft A massive onlay graft the graft itself being broader than the host femur This graft was cut with ball ends

gripped between and supported by the grafts and stable fixation is ensured

"Buried" grafts—Buried grafts driven into beds prepared by the preliminary insertion of a chisel, have been most successfully employed by Brittain [1] in arthrodesing joints (Figs 21 and 22) This technique depends, however on the graft being supported on all sides by cortical or firm cancellous bone, and its value in the treatment of fractures is limited although the use of bone pegs is based on exactly the same principles

FIG. 21

FIG. 22

FIGS. 21 and 22.—"Buried" graft. The graft bed is prepared by the insertion of a chisel (21), and the graft is driven along the chisel track (22).

Bone pegs—An autogenous bone peg is driven into a drill hole across and as nearly as possible at right angles to the fracture line Usually the main function of such pegs is mechanical, and their osteogenic value is of secondary importance In these circumstances the peg is best prepared from hard cortical bone, which is strong and can be shaped in a bone mill or with a file to fit the drill hole accurately Properly used, these pegs effectively immobilise the fracture but their osteogenic value is almost certainly small They often appear unchanged on radiological examination long after the fracture has united Pegs cut from the ilium and consisting of soft cancellous bone, have a much higher osteogenic value but are friable and soft and must be inserted carefully and protected from any subsequent strain Such pegs are only suitable for use in fractures in which there is no tendency to displacement Attempts to combine these functions by preparing a peg consisting of both cortical and endosteal bone are not very satisfactory The endosteal bone is so soft that it crumbles during the preparation and insertion of the peg leaving a cortical portion which is too small to fit closely into the drill hole

Bone fragments—Small fragments of bone packed around the fracture or used to fill defects are a valuable source of new bone formation Cancellous bone has the highest osteogenic value and being soft, is easily packed into the required position These fragments have no mechanical function and should always be used in conjunction with some form of graft which effectively immobilises the fracture

Sliding grafts—An alternative method of inlay grafting consists of sliding the graft from one fragment across the fracture If a rectangular graft is used it is smaller than its bed by the width of two saw-cuts to avoid this it should be cut either wedge shaped or with appropriate steps" Grafts produced by this technique are small and often decalcified fixation is not very secure and the method should only be used if no other source of graft is available

"Split-bone" technique.—This method was first described by Gill[3] for fractures of the bones of the forearm The bone is split in two above and below the fracture, the longer fragment being split about twice as far as the shorter The anterior halves of the split portions are removed and the longer piece of bone thus produced is laid across the fracture and fixed with screws The gap left is filled

FIG 21

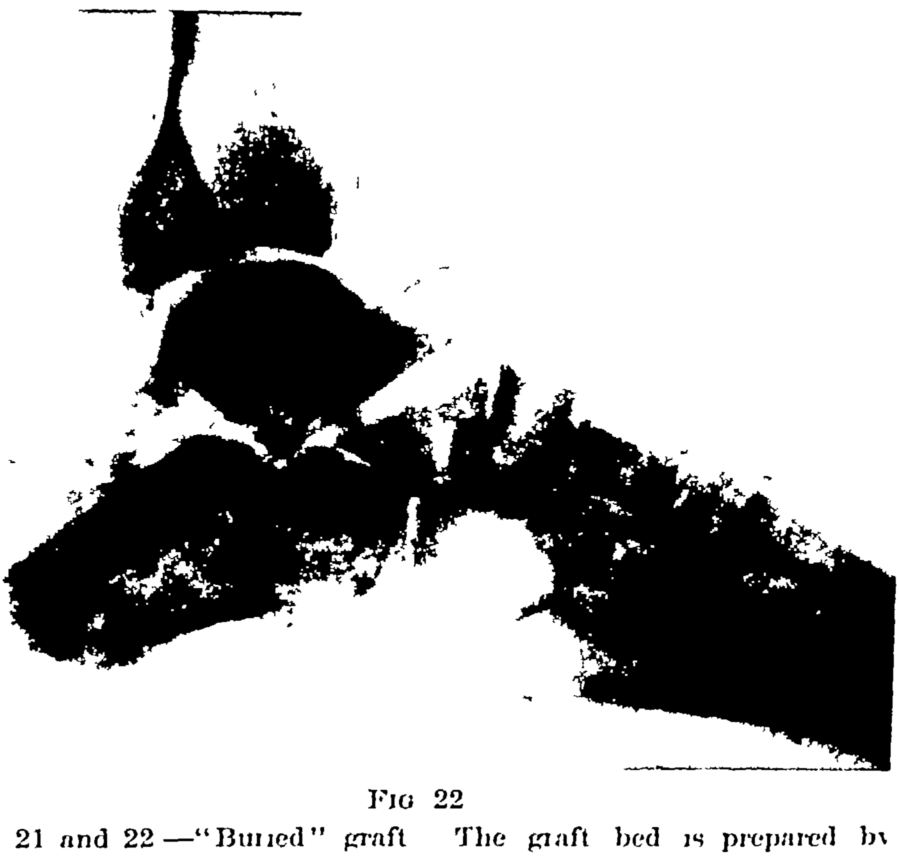

FIG 22

FIGS 21 and 22—"Buried" graft The graft bed is prepared by the insertion of a chisel (21), and the graft is driven along the chisel track (22)

Tibia —So long as it remains necessary to mutilate a previously normal bone to obtain a suitable bone graft the tibia will almost certainly retain its present popularity among orthopædic surgeons

FIG 25 FIG 26 FIG 27

FIGS. 25 and 26 —A tibia six months after removal of a massive graft The defect is not filled by bone

FIG 27 —A tibia six months after removal of a small cortical peg from the crest The defect is still clearly seen.

It is an easily accessible source of strong grafts of a fairly high osteogenic value There are three main types of tibial grafts

1 *The ordinary general purposes graft* —This is cut from the subcutaneous surface between the crest and posterior margin Such grafts are wide enough for most requirements, and can be cut to any desired length and shape

2 *Massive grafts.*—Inclusion of the solid cortical crest greatly increases the strength of the graft. A massive graft, six or seven inches long, consisting of the crest and anterior two-thirds of the subcutaneous surface, can be cut when necessary.

3 *Bone pegs.*—A triangular peg can be cut from the thick cortex of the crest without opening the medullary cavity. Such pegs are strong and, being triangular on section, are easily rounded to any required size.

FIG 28

Fracture of the tibia fourteen days after removal of a small cortical peg

There is much unfounded optimism regarding the regenerative powers of the tibia. I do not believe that after a graft has been removed the tibia of an adult is quickly restored to normal by new bone formation. The defect is filled not by bone but by fibrous tissue (Figs 25, 26, and 27) Removal of even a very small graft is sometimes followed by fracture of the tibia (Fig. 28), showing that the structure of the bone as a whole has been materially weakened. This is ultimately compensated by hypertrophy and the laying down of new trabeculæ in accordance with Wolff's law, but this process takes time (Fig. 29) If too much of the tibia is removed the remaining bone may never hypertrophy sufficiently to restore the strength of the limb to normal.

Ilium.—Grafts removed from the iliac crest consist of soft cancellous bone of a high osteogenic value. As these are not strong enough to be efficient internal splints and must always be combined with some other form of internal fixation their use in the treatment of fractures is limited Because of its high osteogenic value however, iliac bone may be used to graft fractures in which there is no tendency to displacement or in conjunction with tibial grafts in fractures in which a large amount of bone loss has occurred.

Fibula.—A suitable length of the fibular shaft, resected subperiosteally from its middle third, can be used as a graft. As such grafts have a hard outer shell of thick cortex they are revascularised

very slowly and, although they are strong, their osteogenic value is limited

Homologous grafts—Bone grafts can be successfully transferred from one individual to another should the necessity arise The donor should be healthy and free from infection and on no account should a preliminary blood investigation be omitted There is not sufficient evidence to show if this type of grafting is as uniformly reliable as autogenous grafting nor do we know what relation such factors as the blood groups of the individuals concerned bear to the prospects of success

Stored grafts—Bone-grafts need not be used immediately but can be stored under suitable conditions for a considerable period Inclan[3] has reported a high percentage of success with autogenous and homologous grafts stored in citrated blood at between three and five degrees centigrade for periods of from three to sixty three days

Heterogeneous grafts.—The use of heterogeneous grafts has been abandoned Any attempt to transplant a live graft of animal bone is followed by a local and general reaction characteristic of the introduction of foreign proteins into the system

Future developments—There is no doubt that in suitable circumstances bone can be removed under aseptic conditions immediately after death stored and successfully used to graft a fracture The danger that such a graft might have been infected by a terminal bacteræmia does not arise in the case of the sudden death by violence of a previously healthy individual It may well be that the facilities of the Orthopædic Centre of the future will include a 'bank' of stored bone

FIG 20

A tibia one year after the removal of a massive graft The defect has not been filled but the remaining bone has hypertrophied

FIXATION OF GRAFTS

Screws.—Effective fixation is best secured by metal screws driven through the graft and the opposite cortex of the host bone. If these

FIG 30

Adequate and inadequate fixation A fracture of the radius and ulna was first seen four weeks after an open reduction at which the ulna had been wired and the radius grafted The graft used was too small and had been inadequately fixed with loops of wire Re-displacement had already occurred The ulna was exposed, both fractures were reduced by manipulation, and the ulnar fracture was fixed with an adequate graft held by two screws. Ten weeks after operation the ulnar graft is already completely incorporated

screws are inserted well away from the fracture line their presence does not affect the process of union Complications due to the insertion of a reasonable number of stainless-steel or Vitallium screws are extremely rare, while inadequate internal fixation is one of the commonest causes of failure to obtain union after bone-grafting (Fig. 30)

Accurate fitting.—Inlay grafts may fit so accurately in their bed that further fixation is unnecessary. It has even been stated that to contemplate added fixation after insertion of an inlay graft is an obvious insult to the grafting technique I believe that it is always better to reinforce this method of fixation by the insertion of a suitable number of screws.

Autogenous bone pegs.—Bone pegs driven through drill holes penetrating graft and host have been used as a means of fixation. This technique is somewhat tedious and tends to be unreliable

Other methods.—Loops of wire or catgut and various other devices have been used to fix grafts to the host bones. None of these methods is satisfactory or reliable.

CONCLUSIONS

I consider that three main conclusions emerge from a consideration of the relative values of the various types and methods of bone grafting in the treatment of fractures

1. The onlay graft technique is the simplest and most efficient
2. The most effective available grafts are those cut from a previously intact tibia
3. The use of metal screws is the most reliable method of securing internal fixation

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CHAPTER III

PRE- AND POST-OPERATIVE TREATMENT

PRE-OPERATIVE TREATMENT

A BONE-GRAFT is never a matter of extreme urgency and judgment should be exercised in selecting the most favourable time for operation. Various factors may influence this decision, and a period of preliminary treatment is often necessary.

Effects of trauma.—The effects of the soft-tissue injury associated with a simple fracture vary from a comparatively slight local reaction to gross bruising and swelling of the whole limb The statement that between ten and fourteen days after injury is the "safe period" for operation is, like most generalisations, of no practical value On those rare occasions when primary bone-grafting is indicated in simple fractures, operation should be deferred until the immediate effects of injury have subsided. These may be so slight that skin preparation can be started at once and operation carried out three or four days later. A generalised subcutaneous œdema associated with blistering of the skin—the so-called "fracture blisters"—precludes operation for three or four weeks. Effective immediate treatment greatly reduces the local reaction associated with a simple fracture. A firm elastic bandage and adequate splinting prevent gross swelling and blistering. If these complications have been allowed to occur the fracture should be reduced as accurately as possible by manipulation and the limb immobilised in plaster for a week or two. When œdema has subsided the plaster is bi-valved to allow skin dressings and the necessary pre-operative skin preparation.

Effects of immobilisation.—Many fractures in which bone-grafting is indicated have been immobilised for long periods. As a result joints have become stiff and the skin thin and atrophic It is usually possible to dispense almost entirely with all forms of splinting for a week or two prior to operation without producing any change in the fracture which will affect the subsequent bone-grafting During this period the patient concentrates on active exercises to restore joint movement. The marked improvement in the blood supply

and general condition of the limb which follows is associated with better post operative healing and the range of joint movement regained is not entirely lost during the further period of immobilisation necessary after grafting

Shortening—Difficulties arise in bone grafting ununited fractures of the tibia and fibula or femur in which considerable shortening has been allowed to occur Soft tissue contraction prevents the correction at operation of more than about an inch of shortening of long standing If two or three inches of overlap is present it is necessary to remove a considerable amount of bone to effect reduction thus producing permanent shortening of the limb Before operation skeletal traction by a tibial transfixion pin should be instituted and maintained until the overlap is corrected as far as possible Tibial fractures are then immobilised in plaster with the knee slightly flexed and in femoral fractures skin traction is substituted for skeletal traction When the pin track has healed skin preparation can be commenced This preliminary correction of gross shortening by skeletal traction often makes it possible to restore the limb to full length When dealing with fractures which have united with two or three inches of overlap it is well to remember that if the alignment is satisfactory normal function can be restored by a corresponding operative shortening of the other leg This procedure may be more practicable than an attempt to correct shortening by operative reduction of the fracture and bone grafting

Infection.—The dangers of wound infection following bone grafting have already been emphasised Skin lesions or septic foci require appropriate treatment A routine examination of the teeth tonsils and accessory sinuses of every patient in which grafting is contemplated often reveals a previously unsuspected focus

Compound fractures in which there has been infection are particularly dangerous Operation should not be contemplated until all wounds have been soundly healed for at least three months The clinical signs associated with an ununited fracture are similar in many respects to the classical signs of inflammation but a combination of local heat redness and swelling is certain evidence of an active infection This is also indicated by a leucocytosis a raised sedimentation rate or by the presence of a sequestrum or a patchy decalcification of the bone ends on radiological examination Preliminary manipulation has been suggested on the grounds that

this will cause any latent infection to flare and become obvious It may be very difficult, however, to be certain that the reaction following such manipulation is anything more than the normal result of the violent disturbance of an ununited fracture. It is probably better to dispense with all forms of immobilisation for about ten days and encourage the patient to carry out vigorous non-weight-bearing exercises, without submitting the fracture to any gross violence. This régime is not associated with any marked reaction due to the presence of an ununited fracture and is probably quite as effective as a manipulation in "lighting-up" any infection which may be present

When it is remembered how an osteomyelitis may become active years after it apparently has subsided completely it is not surprising that operation on such fractures is occasionally followed by infection in spite of all precautions However, by exercising the greatest possible care in deciding whether or not it is safe to bone-graft a fracture which has previously been infected, it is possible to reduce the incidence of this most disastrous complication to a minimum.

Rehabilitation.—Union of the fracture in good position does not of itself ensure full function of the limb Wasted muscles must be redeveloped and a full range of movement restored to stiff joints. This ultimately depends on the patient's own efforts, for which no amount of physiotherapy is an effective substitute. Indeed, physiotherapy can be actively harmful if it induces the belief that recovery will occur as a result of treatment without any exertion on the part of the patient.

Regular active exercises, both of the injured limb and of the rest of the body, a stimulating environment, and the firm conviction that recovery will surely follow are the essential features of rehabilitation. The immediate mental reaction to any injury is the desire to become well again: rehabilitation in its truest sense must begin at once, and this reaction must never be allowed to fade into apathy. From the patients' point of view, bone-grafting is a milestone in treatment, and before operation they should be convinced that subsequent recovery depends as much on their determined co-operation as on the technique of their surgeon.

Diet.—Any dietetic deficiency delays post-operative healing and bony union. Under ordinary circumstances hospital diets are usually quite adequate, but if there is any reason to suspect that they

may be deficient in any essential constituent this can be provided Calcium is of course an essential factor in new bone formation and although most diets contain an adequate amount the very common practice of prescribing calcium for patients with severe fractures is an added safeguard Under present circumstances Vitamin C deficiency is a more real possibility Before operation it is wise to make sure that the patient is saturated with this vitamin by administering ascorbic acid by mouth and subsequently testing its concentration in the urine

Skin preparation —In an orthopædic department one member of the nursing staff is trained to carry out preparation of the skin prior to operation This nurse is not allowed under any circumstances to participate in the treatment of patients with infected wounds

Full aseptic ritual, with a sterile gown mask, and gloves is observed during the actual skin preparation Four days before operation the whole limb is thoroughly washed with ether soap shaved dried with surgical spirit powdered with boracic powder, and then wrapped in a sterile towel which is fixed firmly in position with a bandage The next morning this is removed and the whole limb is thoroughly painted with flavine in spirit particular attention being paid to the interdigital clefts and a similar dressing is applied This process is repeated in the evening, on the morning and evening of the two succeeding days and finally on the morning of operation

Skin reactions to flavine in spirit are exceptional Should they occur preparation is discontinued until the reaction has subsided and then washing with ether soap thorough drying and powdering with sterilised boracic powder is substituted for painting with an antiseptic This is well tolerated by the most sensitive skin

POST-OPERATIVE TREATMENT

Immobilisation.—Internal fixation by means of a bone-graft although mechanically stable, should always be supplemented by external fixation The graft prevents movement between the bone ends and external fixation protects the graft from mechanical stresses The recent tendency to dispense with all forms of immobilisation after internal fixation may be practicable when metal plates and transfixion screws are used although plates have been known to bend or break, and screws to work loose After bone grafting however external fixation is essential

In almost all fractures a closed plaster is the most effective method of immobilisation When post-operative swelling is to be expected plaster is best applied over a layer of wool. The amount of padding used depends on the type of fracture which has been grafted and on the personal preference of the surgeon. Plasters, especially padded plasters, become loose two or three weeks after operation and should then be changed Immobilisation is continued until the fracture has united by bone.

Dressing of wounds.—The dressings applied at operation are left undisturbed under plaster. When this is changed for the first time the sutures are removed. There is no necessity to change the plaster for the sole purpose of doing this, however, as the sutures can be left in position for three or four months if necessary.

Post-operative complications.—The immediate post-operative period is not usually associated with any special problems. Occasionally the following complications may occur —

SHOCK —This may follow grafting of fractures of the femoral shaft or arthrodesis of the spine. Shock is usually slight and responds quickly to treatment by heat, morphia, and intravenous saline or blood plasma.

PAIN —Post-operative pain is not severe and is easily controlled by morphia.

HÆMORRHAGE.—A tourniquet is used whenever possible during operation and I do not remove the tourniquet until the wound has been sutured and a pressure bandage and plaster applied Although subsequent staining of the plaster occurs I have never seen a severe hæmorrhage after operation. Should such a hæmorrhage occur a full dose of morphia is given, the plaster is removed, and an effective pressure bandage is applied When it is certain that bleeding is effectively controlled the plaster is reapplied and a transfusion of not more than 1000 c c of fresh or stored blood is given.

SWELLING —Swelling does not commence for about twelve hours and reaches its maximum between twenty-four and forty-eight hours after operation. After bone-grafting patients are nursed with the affected limb elevated and are encouraged to persist with finger or toe exercises. The digits are inspected regularly for evidence of impairment of circulation The danger signals are blue-grey or greyish-white discoloration, loss of sensation or movement, or gross swelling If the blood supply is threatened by pressure due to

swelling the plaster is split along its whole length on each side of the limb and if necessary the pressure bandage is completely divided in the same line This relieves symptoms at once and should never be delayed in doubtful cases Neglect of these precautions is associated with such serious consequences that it is wise to insist that the condition of the digits be recorded in writing every three hours for the first seventy two hours after bone grafting

PARALYSIS —Occasionally a nerve palsy, most commonly of the radial or external popliteal nerve follows bone grafting This may be due to the tourniquet to trauma at operation, or to pressure If swelling is present the plaster is bi valved In the absence of swelling windows are cut over any areas in which the affected nerve is exposed to pressure Tourniquet palsies and those due to pressure or traction recover in from six to sixteen weeks No special treatment is necessary but the affected digits should be put through a full range of passive movement at least three times a day to prevent joint stiffness This is the only circumstance in which passive movement is indicated in the post-operative treatment of fractures

INFECTION —Infection is indicated by pyrexia, throbbing pain in the region of the wound, swelling and tenderness of the lymphatic glands draining the limb and later by purulent discharge Should infection occur full doses of sulphanilamide are given by mouth or intramuscular injection and if the local symptoms are severe the plaster is removed and the wound inspected It may be necessary to remove some or all of the sutures to release pus under tension After dressing with vaseline gauze plaster is reapplied and treatment is continued on the lines first suggested by Winnett Orr

Chemotherapy —The value of the sulphonamide group of drugs in the control of bone infections particularly in compound fractures is established At the same time it appears to me that there is at present a dangerous tendency to rely too much on the lavish use both local and general of these compounds to prevent post-operative infection with a corresponding decrease in the meticulous care necessary in the selection of cases pre-operative skin preparation and aseptic theatre technique The results of any such tendency can only be disastrous

Provided that this is realised the controlled exhibition of this group of drugs can do nothing but good Some surgeons prefer to administer a full course of one of these compounds by mouth or

intramuscular injection as a routine post-operative measure My own preference is to do this only after operation in compound fractures in which there has been at some time evidence of infection, or in patients in which a post-operative pyrexia or rise in pulse rate suggests the possibility of a local inflammatory reaction.

Rehabilitation.—The importance of functional activity, not only of the injured limb but also of the rest of the body, cannot be over-emphasised. Active exercises are recommenced immediately after operation and are increased until they merge into a gradual return to full activity.

CHAPTER IV

OPERATIVE TECHNIQUE

SIMPLICITY effectiveness and a minimal amount of damage to normal structures are the features of any sound technique for bone grafting The use of a large number of instruments and mechanical devices is quite unnecessary It is convenient to describe in a general way certain details of operative procedure

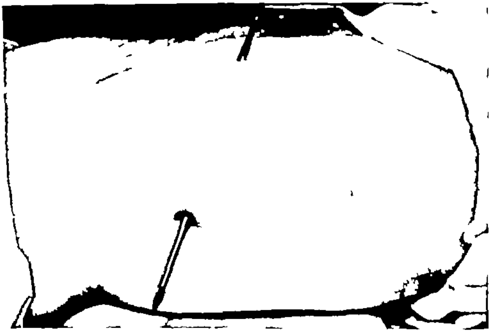


FIG 31

Pin in position. The tourniquet applied immediately below and parallel to the inguinal ligament, is kept from slipping down the thigh by the protruding ends of the pin.

No-touch technique—Bone and joint cavities are less resistant to infection than any other body tissue There is no 'margin of safety' when operating on these structures Scrupulous asepsis is necessary and it is almost fifty years since Lane[1] advocating internal fixation in simple fractures insisted on the use of a 'no touch' technique during operation The essential feature of this technique is that neither the wound nor anything that is introduced into it is touched by the gloved hand or allowed to come into contact with

A

B

C

D

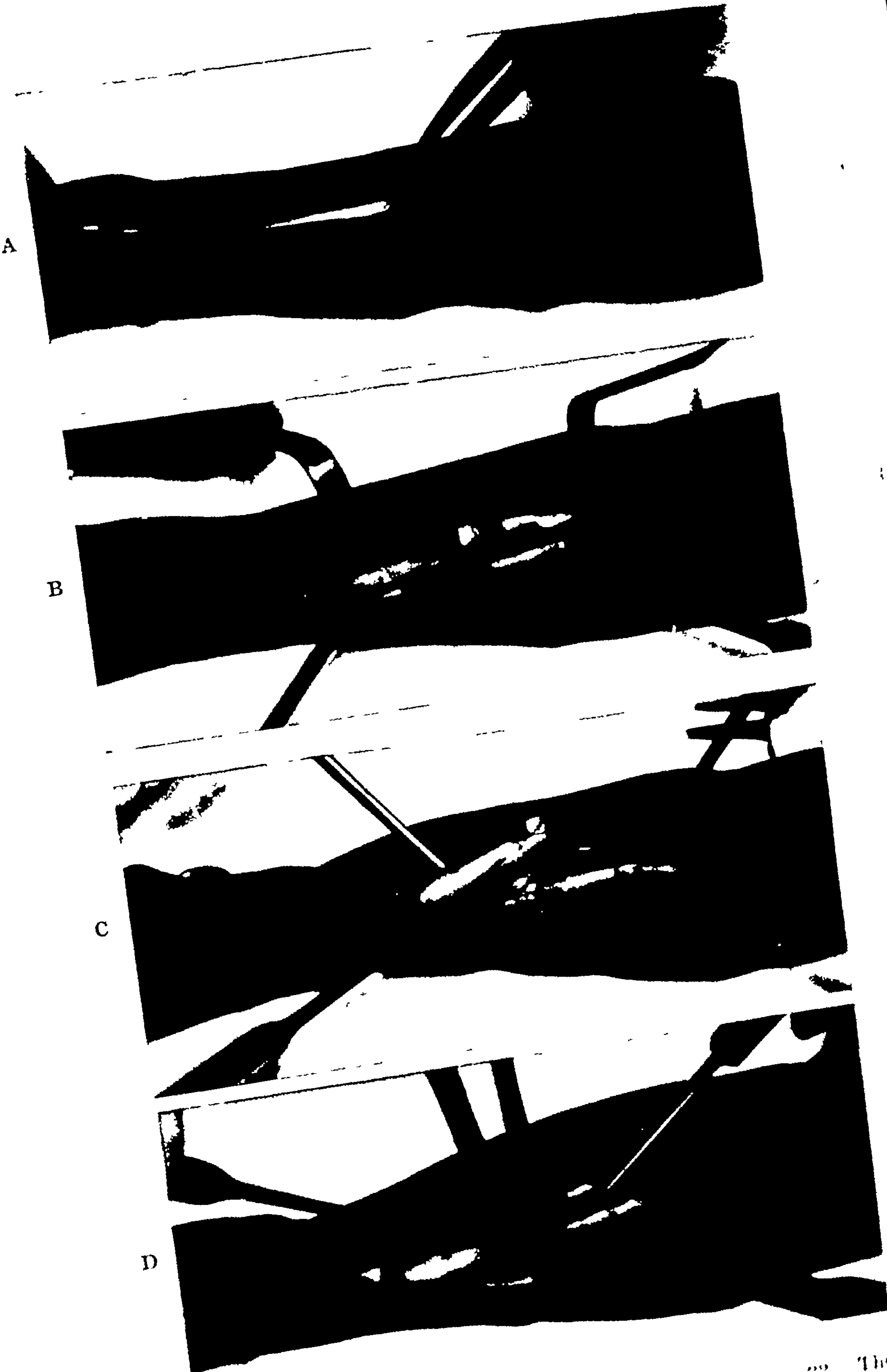
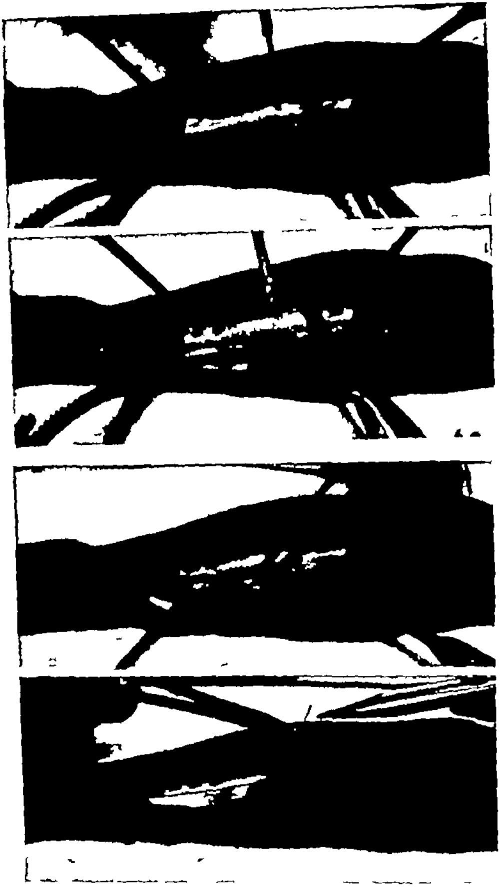


FIG. 22. The

... incision is made through the adherent stockinet ... the periosteum ... incised ... strip ...
... traction ... of the graft ...



E

F

G

H

stages of a bone-graft.

E. The graft is placed in position held with bone clamps, and screw holes are drilled.

F The graft is fixed with screws. (Note the box-spanner type of screw-driver)

G The clamps are removed and bone chips are packed around the fracture.

H. The periosteum and muscles are sutured back into position.

the skin of the patient This refinement of the usual aseptic ritual has been generally adopted by orthopædic surgeons. In other countries some schools have given up the rigid use of the technique and claim that their results have not been affected. This has not been the general experience in this country, however, and I believe that a sound "no-touch" technique is essential in operative orthopædics.

Tourniquets.—The use of a tourniquet makes bone-grafting easier and prevents blood-loss during operation. A properly applied tourniquet exerts an even pressure over a broad area and does not directly compress any vessel or nerve against underlying bone. It is put on after the patient has been anæsthetised but before pre-operative dressings have been removed.

For the arm a pneumatic tourniquet is applied over the middle or junction of middle and upper thirds of the humerus The limb is held vertical and a sterile towel is wrapped evenly around the arm to serve as a basis for the tourniquet. A soft-rubber bandage is firmly applied from the fingers to the lower edge of this towel, the pneumatic tourniquet is placed in position, and the pressure is raised to 180 mm Hg., and maintained at this level throughout operation This type of tourniquet can safely be left in position, for from two to two-and-a-half hours if necessary.

A rubber bandage applied over a towel at the junction of the middle and upper thirds of the femur is used for the leg The technique of application is the same as for the arm and the bandage covers about six inches of the thigh For fractures of the femoral shaft a special type of tourniquet is necessary to allow access to the bone. A very strong Steinman's pin is driven through the muscles above the great trochanter so that it protrudes about two inches in front and behind (Fig. 31). A rubber bandage applied to the upper thigh is prevented from slipping down by this pin, and it is possible to expose most of the femoral shaft with a tourniquet of this type in position. Tourniquets can be left on the leg for between two and three hours if necessary.

The application of a tourniquet is a very important step in the operation and should be carried out by the surgeon or one of his assistants A "tourniquet-book" is kept in the theatre, one of the theatre staff is responsible for recording the time at which the tourniquet is applied and removed and for informing the surgeon

how long the tourniquet has been in position every fifteen minutes throughout the operation

Position of patient.—The ease with which a fracture can be exposed often depends considerably on the position of the patient, and this should be suitably adjusted before commencing operation

Skin towels—The patient's skin must be kept completely covered with sterile towels throughout operation The limbs are best protected with a roll of sterile stockinet, applied after the skin has been painted with an antiseptic A suitably large area is then swabbed with a sterile adhesive solution and the incision is made through the stockinette which remains adherent to the skin around the wound (Fig 32 A) Other incisions are screened by sterile towels clipped to the skin edges These should be fixed with towel clips and not with skin clips of the Michel type which may easily become dislodged during operation

Exposure of fracture—The incision must be long enough to allow adequate access to the fractured bone It is not true that ' nature heals a large incision as easily as a small one but the trauma from retraction in an endeavour to obtain a sufficient exposure through an inadequate incision is much greater than that caused by extending the incision

The approach is planned so as to expose the fracture with a minimal amount of disturbance of normal structures Advantage is taken of intermuscular planes particularly those between muscle groups No difficulties arise in the case of bones with a subcutaneous surface and Henry [1] has worked out admirable methods of exposing the other long bones

When the various structures have been divided or separated so that retraction reveals the bone in the depths of the wound the periosteum is cleanly divided for a suitable distance above and below the fracture by a single incision (Fig 32 B) Using an elevator the periosteum is stripped until the bone is sufficiently exposed Spikes introduced between periosteum and bone act as retractors and open up the wound so that the fracture is completely exposed (Fig 32 C)

The amount of periosteal stripping which is permissible is rather controversial It has been stated that as the periosteum is an important source of blood supply stripping should be as limited as

possible and that the periosteum should always be left attached to at least one-third of the circumference of the bone. On the other hand, it is sometimes necessary to expose a large area of the shaft of a long bone completely. Provided that the periosteum is cleanly incised and carefully stripped, so that it forms a continuous sheath which can be sutured back in position at the conclusion of operation, it seems certain that a reasonable amount of stripping does no permanent damage.

In bone-grafting it is necessary to separate the periosteum completely for an inch or so above and below the fracture so that the fractured surfaces can be cleared of fibrous tissue and reduction effected. It is also necessary to strip the periosteum from about half the circumference of the bone for a further distance sufficient to allow preparation of the graft bed I am sure that exposure of the bone in the subperiosteal plane should always be adequate, and that such an exposure is not associated with any serious disturbance of blood supply.

Application of graft.—When the fracture has been reduced the fragments are fixed with bone-holding forceps while the graft bed is prepared (Fig. 32, D). It is important that reduction be maintained while this is being done, so that the bed shall coincide on both fragments. The graft is then placed in position and fixed with self-retaining clamps (Fig. 32, E).

Screw fixation.—The next step is to fix the graft firmly in its bed with screws If fixation is adequate the reconstructed bone is weakest at the point where the graft crosses the fracture line. Here its strength depends on the size and nature of the graft itself and not on the number of screws used to hold it in position. It is, therefore, unnecessary and even harmful to crowd as many screws as possible into the graft Two screws in each fragment are all that is necessary for ordinary grafts, and the most massive graft can be firmly fixed by three screws in each fragment.

The insertion of a metal screw into living bone is not comparable to the insertion of a similar screw into wood. In bone the screw must grip by its threads only. If it compresses the adjacent bone pressure absorption will occur and the screw becomes loose. The screw should therefore be of uniform thickness, of the "self-tapping" type, and should have fairly deep threads It is inserted in a drill hole equal or only slightly smaller in diameter than its central core

This preliminary drill hole should be smaller in soft bone than in hard

I regard the ordinary screw-driver, which depends on a thrusting force to maintain contact between its blade and the slot on the head of the screw as a most unsatisfactory instrument for orthopædic surgery None of the so-called 'self retaining' devices prevent it slipping nor do they abolish the necessity to maintain considerable pressure to keep the blade in position Besides these mechanical disadvantages it is essentially wrong to attempt to "drive" a self tapping screw—it should be "screwed" home

The use of screws made of non ionisable metal has become increasingly popular Unfortunately the metal is so brittle that it cannot be worked and these screws are cast Consequently their threads are very fine and flaws are common These disadvantages almost outweigh their advantages

I have had a modified type of Sherman self tapping screw prepared from "non toxic" steel This screw has an oblong head with flattened sides which fits into a cavity in a "screw driver" which is really a modified box-spanner Practically no thrust is necessary to keep the head engaged and the screw can be "screwed" home with no difficulty

To fix a graft with these screws a suitable number of preliminary drill holes are made through graft and host (Fig 32 E) using a 7/64 inch drill As the graft is slightly harder than the host bone the drill holes in the graft are then enlarged to an eighth of an inch Finally the holes are touched with a 9/64 inch drill to facilitate starting the self tapping screw and to allow slight counter-sinking of its head A bone calibrator is used to measure the exact length of screw necessary to penetrate the graft and opposite cortex of the host bone and the screw is inserted (Fig 32 F) Once the screw is "home" further penetration is prevented by contact between its head and the graft, and any effort to twist it a little tighter simply strips its threads from the bone and renders it useless

This technique is applicable to any type of screws of uniform thickness provided the preliminary drill holes are of the correct size

Electrolytic reaction has been stated to be the cause of a high proportion of screws quickly becoming loose and ineffective and the use of non ionisable metals hailed as a solution to all such difficulties I feel sure that the technique of insertion rather than

the composition, is the important factor in the subsequent efficacy of metal screws.

Radiographs during operation.—Accurate apposition of the fractured surfaces does not necessarily entail normal alignment of the fragments. It is not always possible to be sure that alignment is satisfactory by inspection of the area of bone exposed at operation particularly in the case of a long bone with a curved shaft After the graft has been fixed the wound is covered, and radiographs are taken to check reduction. This precaution should never be neglected Subsequent function depends on accurate alignment, and an angulation which can be corrected in a few minutes if detected during operation presents a very different problem if first discovered a few days later.

Local chemotherapy.—The value of local chemotherapy in operation on closed fractures does not appear to me to be established, and the introduction of a large amount of one of the sulphonamide compounds in powder form into a surgical wound is not without danger.

When operating on a compound fracture in which there has been, at any time, an infection it is my practice to dust the wound lightly and evenly with sterilised sulphonilamide powder before closing the periosteum. I do not, however, do this as a routine measure in all cases.

Closure.—When the graft has been fixed in position and bone chips packed around the fracture (Fig 32, G) the wound is sutured in layers The periosteum is closed as accurately as possible with interrupted sutures of fine catgut, the muscles are approximated in a similar way and the skin is closed with silkworm gut (Fig 32, H)

Immobilisation.—A pressure bandage is applied and the fracture is immobilised usually by the application of plaster. The type of plaster and the amount of padding used depend on the site of the fracture, on the danger of re-displacement, and on the amount of swelling which may be expected When immobilisation is completed the tourniquet is removed

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CHAPTER X

CUTTING AND PREPARATION OF GRAFTS

It is usually best to cut and prepare a suitable graft before exposing the fracture While time can be saved if an experienced assistant is available to procure the graft this is not by any means the least difficult or important part of the operation

TIBIA

The tibia is most accessible with the patient supine the leg being externally rotated at the hip so that the subcutaneous surface of the bone is horizontal

When the patient is anæsthetised and a tourniquet in position the pre operative dressings are removed After painting with an antiseptic the skin from the toes to the knee is covered with a roll of sterile stockinet and adhesive solution is applied over the subcutaneous surface of the tibia

ORDINARY GRAFTS —A vertical incision two inches longer than the graft required is made over the centre of the subcutaneous surface of the tibia The periosteum is divided in the same line with transverse cuts about an inch long at the extremities of the incision and is gently stripped from the antero-medial surface of the bone with an elevator

The graft is cut with a motor-driven saw Cuts should always be made from right to left, as the bone-saw rotates in such a way that it divides the cortex from below upwards when cutting in this direction and consequently does not tend to jump but is actually forced deeper into the bone by the cutting action A single saw is used unless it is necessary to have a graft of a predetermined uniform width in which case a suitably adjusted double saw is used

The longitudinal cuts are made first with a 1¼ inch-diameter blade care being taken to avoid the hard cortical crest and posterior margin of the bone (Fig 88) If a saw fitted with a high speed shaft to take a slotting burr is not available a ¾-inch-diameter blade is used to complete the upper and lower transverse cuts It is essential

that the saw should not be allowed to "jump" during this latter manœuvre, important structures have been cut as a result of this accident Unless a slotting burr or a small-diameter blade is available it is better to use a series of drill holes to make the transverse cut

When the cortex is completely divided the graft is loosened by inserting an osteotome gently at intervals along the saw-cuts, and is then lifted out of its bed and placed in saline When the graft has

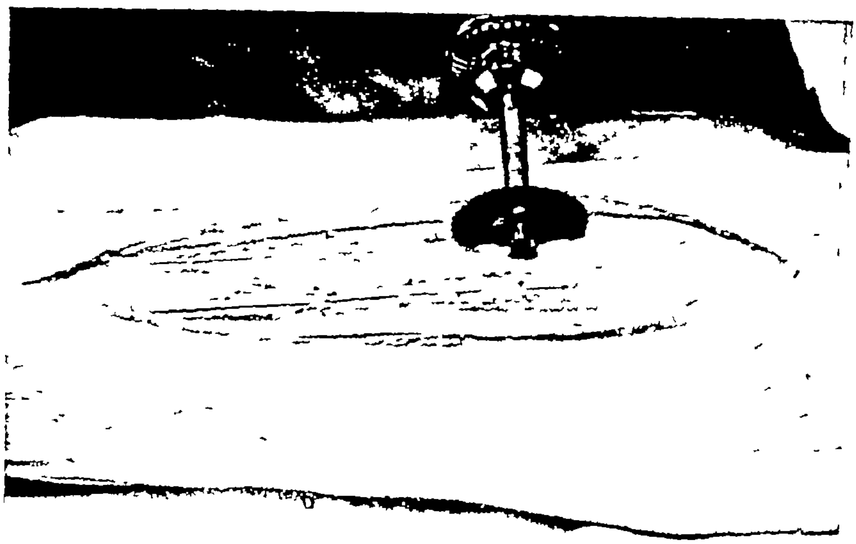


FIG 33

Cutting an ordinary graft from the tibia The vertical saw-cuts are made in the centre of the subcutaneous surface, the crest and posterior margin being avoided

been removed a suitable amount of soft cancellous bone is scooped out of the medullary cavity, stored in saline and subsequently packed around the fracture after the graft has been fixed in position

The periosteum is then repaired with interrupted sutures Care is taken to approximate its edges accurately and, provided it has not been damaged by the preliminary stripping it is possible to close this layer completely. The skin is sutured and a pressure bandage is applied before the tourniquet is removed

CORTICAL BONE PEGS.—A three-inch incision is made over the tibial crest. The periosteum is stripped from the anterior sharp margin for about two inches and a section of bone is removed with a single saw (Fig 34, A and B) The triangular fragment thus produced is placed in saline The periosteum and skin are sutured and a pressure bandage is applied

MASSIVE GRAFTS.—The skin incision extends for about two-thirds

of the length of the tibia The periosteum is divided in the same line and completely stripped from all aspects of the bone Two bone levers inserted between the periosteum and the posterior surface of the tibia and slid to the extremities of the wound act as retractors (Fig 35, A)

The first longitudinal cut is made on the antero lateral surface of the tibia immediately behind the crest the saw blade being kept parallel to the antero-medial surface (Fig 35 B) A second longitudinal cut is made at the junction of the anterior two thirds and

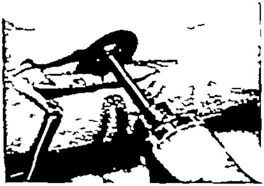


FIG 31 A

FIG 31 B

FIGS 31 A and B —A cortical peg is cut from the tibial crest with a saw (A) and is triangular on section when detached (B)

posterior third of the subcutaneous surface These are joined by transverse cuts which completely divide the crest and the graft consisting of the crest and anterior two thirds of the antero medial surface is detached with an osteotome (Fig 35 C) The inclusion of more than the anterior two-thirds of the subcutaneous surface produces an unnecessarily broad graft

The periosteum is easily closed as the total diameter of the tibia has been reduced The skin is sutured a pressure bandage applied and the tourniquet is removed

After-treatment of the donor leg—The removal of even the smallest graft weakens the tibia which may subsequently be fractured by trivial violence The defect is not filled by regeneration' but the structural weakening is compensated by hypertrophy of the remaining portion of the bone Until this has taken place the tibia must be protected

Weight bearing is not permitted for three weeks after the removal of the graft At the end of this time the pressure bandage is taken off and the sutures removed from the wound A dressing is

FIG 35, A

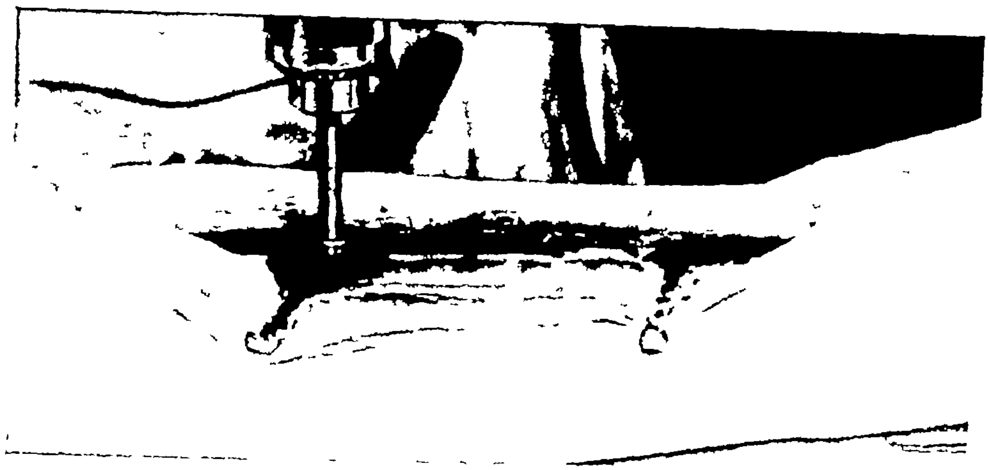


FIG 35, B

FIG. 35 C

FIGS 35, A, B and C.—*Cutting a massive tibial graft* The bone is completely exposed spikes passed between the periosteum and the posterior surface acting as retractors (A) The first cut is made on the antero-lateral surface immediately behind the crest (B) A second cut is made along the junction of the anterior two thirds and posterior third of the subcutaneous surface and when the end cuts are completed a massive graft consisting of the crest and anterior two thirds of the subcutaneous surface, is detached (C)

applied and the tibia is protected by a plaster gaiter, which is moulded to the anterior two-thirds of the leg from the malleoli to the tibial tubercle and held in position by a firmly applied crepe bandage It might be argued that a complete below knee or even mid thigh plaster is necessary to afford full protection, but I believe that the gaiter is adequate and it has the great advantage of permitting full knee and ankle movement It is changed when necessary and is retained for eight weeks

FIBULA

The fibula is best approached from its lateral aspect and is most easily accessible with the pelvis tilted and the donor leg fully internally rotated by suitably placed sandbags A tourniquet is used and the patient's skin is protected in the usual way

The fibula is identified by palpation and a six inch skin incision is made over the lateral aspect of its middle third The plane between the peronei in front and the gastrocnemius and soleus behind is identified and these muscle groups are separated until the sharp lateral edge of the bone is exposed The periosteum is incised and stripped from all aspects of the middle third of the shaft The bone is divided with heavy bone cutting forceps and a suitable length of the shaft is removed and placed in saline The periosteum is sutured the muscle layers approximated and the skin incision is closed

No subsequent immobilisation or restriction of weight bearing is necessary In children the fibular shaft always regenerates after sub-periosteal resection and there is usually some degree of re generation in adults Even if this does not take place however the removal of the middle third of the fibula has no adverse effect on the function of the limb

ILIUM

Grafts can be cut from any part of the iliac crest the anterior half being the most easily accessible The pelvis is suitably tilted and fixed with sandbags and a skin incision about two inches longer than the graft required is made over the subcutaneous margin of the crest Bleeding points are ligatured and the wound is screened with skin towels There is no true periosteum on the iliac crest and the attached muscles are separated from the bone by sharp dissection When the crest is sufficiently exposed the graft is cut with a chisel

This presents no difficulty; the bone is so soft that it is quite unnecessary to use a saw. The first cut is made on the upper aspect of the crest, the chisel being held parallel to the inner surface of the bone, and the thickness of the graft is determined by the distance of this cut from the outer rim. A second cut is made on the outer surface of the ilium parallel and a suitable distance below the crest, which is then divided at the extremities of these cuts The graft, consisting of the outer part of the crest and the bone immediately below it, is easily lifted from its bed The muscles which have been detached from the crest and outer aspects of the bone are carefully approximated with interrupted sutures of No 4 catgut and the skin is closed Dressings are applied and left in position for fourteen days, when the skin sutures are removed. No form of immobilisation is necessary and the patient is allowed to begin weight-bearing two weeks after the operation.

PREPARATION OF GRAFTS

Grafts are kept in saline until the graft bed is prepared. Before insertion a graft is shaped so that it lies evenly in its bed, leaving no projecting spikes or sharp corners. A small vice attached to a wooden stand, both of which are sterilised by boiling in the usual way, is invaluable for holding grafts during the shaping process, and I believe that a graft can be more rapidly and accurately shaped with a coarse file than by any other method (Fig 36)

Tibial grafts.—A tibial graft consists of an outer layer of hard cortex with a variable amount of soft cancellous bone on its inner surface The use of a correctly adjusted double saw should ensure accurate fitting when the inlay technique is used and such grafts require little shaping Onlay grafts need not be cut to such an exact size, but the sharp outer edges of the cortical portion must be rounded off and their ends must be flattened so that they do not project as "steps" when the graft is in position It is very important that the soft inner layer, which has a high osteogenic value should not be removed in an attempt to make the graft lie flat in its bed Any cortical projections such as occur when the saw-cut has encroached on the crest or posterior cortical margin, are trimmed off with nibbling forceps and the soft cancellous layer is flattened by compressing the graft with broad sequestrum forceps or in the vice Any portions of soft bone which become detached during

this process are preserved and subsequently packed around the fracture

Tibial pegs.—Cortical pegs are triangular on section when cut from the tibial crest If a bone mill is not available the peg is gripped in the vice and rounded to the required size with a file A metal ruler with graduated perforations is used to measure the diameter of the peg

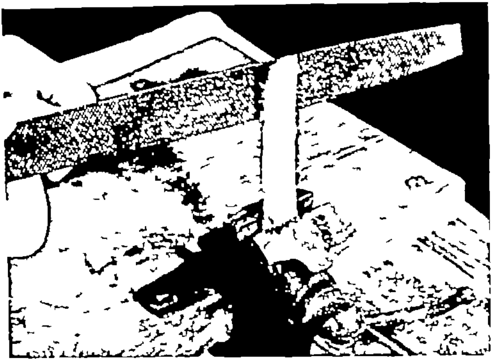


FIG 30
Shaping the graft which is held in a sterilised vice and shaped with a file

Fibular grafts.—The fibular shaft is roughly triangular on section with well marked ridges made by muscle attachments The outer cortex is hard smooth and relatively impermeable to capillary growth The graft is shaped to fit its bed with a file the outer cortical layers being removed or roughened to facilitate revascularisation

Iliac grafts—Iliac grafts are very soft and easily worked but tend to crumble or break during preparation These grafts are curved due to the shape of the iliac crest and for this reason are rather difficult to shape satisfactorily This also applies to iliac bone pegs and considerable care is necessary to avoid breaking these pegs during their preparation

"Boiled" grafts—On several occasions I have seen grafts boiled

for a few minutes before being inserted. Their subsequent behaviour was apparently normal: there was no delay in union or in incorporation of the graft. While I do not advocate boiling as a routine measure, I consider that such cases prove conclusively that an autogenous bone-graft does not live and "take," and that the heat produced by cutting with a bone-saw or by filing has no important influence on the efficacy of such grafts.

CHAPTER VI

FRACTURES OF THE SPINE

THE results of treatment of fractures of the spine by conservative methods are in general excellent The essential features of treatment are reduction by postural methods, immobilisation in a plaster jacket and graduated exercises to build up a strong spinal musculature Surgical arthrodesis of the spine is occasionally employed as a late measure usually to relieve pain which is by far the commonest source of disability after these injuries

The types of fracture commonly associated with subsequent disability are easily recognised and there is considerable evidence to show that in such fractures the period of treatment is substantially reduced and ultimate results improved if reduction is combined with immediate arthrodesis of the spine

FRACTURES IN WHICH IMMEDIATE ARTHRODESIS IS INDICATED

1 Comminuted fracture of vertebral body with rupture of intervertebral disc.—About ten per cent of vertebral body fractures in which there is no spinal cord injury are of this type A localised flexion force impacts the body of one vertebra on the vertebral body below with sufficient violence to produce a comminuted fracture of the lower body and a rupture of the intervertebral disc between with consequent narrowing or obliteration of the intervertebral space (Figs 37 and 38)

The reduction of such fractures by hyper-extension of the spine is commonly imperfect the shape of the comminuted vertebral body is not restored to normal nor is the intervertebral space fully opened up (Figs 39 and 40) After reduction a prolonged period of immobilisation is necessary to permit consolidation of the vertebral body and it is doubtful if healing of the ruptured disc ever occurs

A high proportion of these fractures are followed by persistent local pain becoming worse after exercise In some cases a bony ankylosis between the vertebral bodies occurs spontaneously and when this ankylosis becomes solid pain is relieved

FIG. 37

FIG. 38

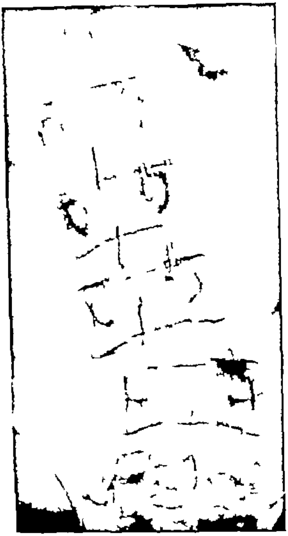
FIGS. 37 and 38.—A comminuted fracture of a vertebral body, with obliteration of the intervertebral space immediately above.

FIG. 39

FIG. 40

FIGS. 39 and 40.—A comminuted fracture after attempted reduction by postural methods. Although the spine is held in extension the shape of the vertebral body has not been restored to normal, nor has the intervertebral space been opened up.

For this reason it seems logical to combine the initial reduction with a localised spinal fusion and the results of treatment on these lines are most encouraging



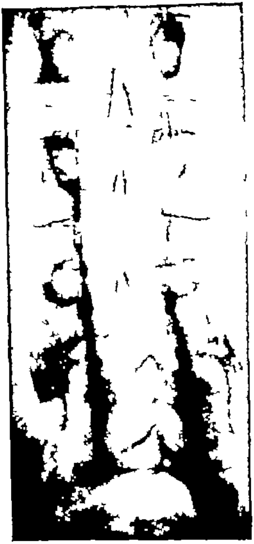


FIG 41 FIG 42

FIG 41 —An intervertebral dislocation with interlocked articular processes.
FIG 42 —The dislocation shown in Fig 41 after open reduction and arthrodesis

2 **Fracture-dislocations with locking of articular processes and without spinal cord injury** —Intervertebral dislocation may be accompanied by interarticular dislocation without fracture of the articular processes (Fig 41) In these circumstances any attempt at manipulative reduction is dangerous Not only does locking of the displaced processes render reduction by manipulation extremely difficult but any movement of the spine tends to increase the

intervertebral displacement and stretch or crush the spinal cord or cauda equina.

Operative reduction is indicated and consists of exposing and excising the ascending articular process of the lower vertebra on the side towards which the spinous processes of the upper segment of the spine are displaced or rotated. This removes the bony obstacle to reduction, which can then be effected by gradual hyper-extension of the spine.

Removal of this articular process permanently disorganises the intervertebral articulations, and, provided there has been no spinal cord involvement, should be followed by local arthrodesis of the spine (Fig. 42).

PRINCIPLES OF OPERATION

The aim of operation is to immobilise permanently the affected area of the spinal column by producing a bony block between the neural arches of the vertebræ involved. This is done by the introduction of two bone-grafts into beds prepared on the posterior surface of the laminæ and lateral aspects of the spinous processes.

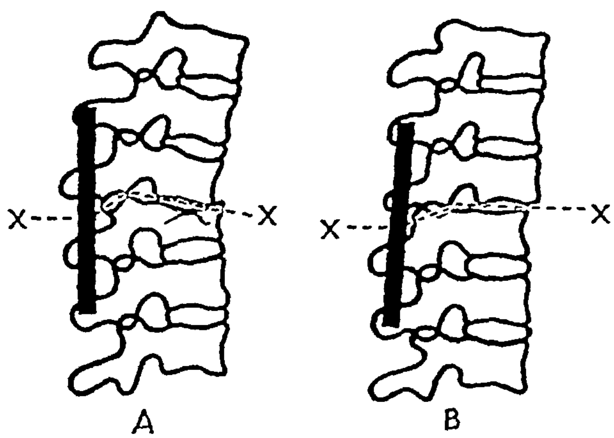


FIG 13

The site of the graft and the area of spine to be arthrodesed in a comminuted fracture (A) and in a fracture-dislocation (B)

The length of spinal column which should be arthrodesed is important. An arthrodesis is ineffective if too short, and if too long permanently reduces spinal movement. Moreover, if too long a graft is used it may subsequently be fractured by muscle action.

It is essential to realise that the centre of an arthrodesis should be an intervertebral space and not a vertebral body. In comminuted fractures the immobilised area is centred around the space in which the disc has been ruptured, in fracture-dislocations around that through which dislocation has occurred. An adequate arthrodesis includes two vertebræ on each side of the affected space. This means that a segment of the spinal column consisting of four vertebræ and three intervertebral spaces is immobilised (Fig. 13). This does not

seriously impair the mobility of the spine as a whole and does not entail the use of grafts long enough to be liable to subsequent fracture

PRE-OPERATIVE TREATMENT

Adequate temporary immobilisation of the spine should be established as soon as possible after injury This is best done by means of anterior and posterior plaster shells comminuted fractures being immobilised in extension and fracture dislocations in the neutral position

As with any other suspected spinal injury, on admission to hospital the patient is nursed flat on the back in a bed with a thin mattress made rigid by fracture boards Radiographs can be taken without moving a patient from bed or even altering his position

When the diagnosis has been established the patient is taken to the plaster theatre on his bed In comminuted fractures the spine is gradually extended by placing sandbags under the patient at the level of the fracture in fracture-dislocations this manœuvre is omitted

A well padded anterior plaster shell extending from the top of the sternum to the lower third of the thighs is constructed When the plaster has set this shell is applied the patient is rolled on his face and a similar posterior shell is constructed

The patient is subsequently nursed either in the anterior shell which permits pre-operative skin preparation and prevents the development of pressure changes of the skin of the back and buttocks or in the posterior shell which is rather more comfortable It is generally convenient to use the posterior shell at night and the anterior shell for long periods during the day

Operation is carried out when the immediate effects of injury have subsided

LOCALISATION OF LEVEL OF INJURY

It can be surprisingly difficult to localise the level of injury during the actual operation and any error results in the graft being placed too high or too low

As has already been pointed out, the centre of the arthrodesed area of the spine should be an intervertebral space The centre of the graft should therefore lie between the spinous processes of the vertebræ immediately above and below this space and the graft

should be in contact with four processes. It must also be remembered that because of the relative positions of the bodies and spinous processes of the vertebræ the centre of the graft lies at a lower level than the affected intervertebral space (Fig. 43).

On the day prior to operation the patient is placed in the anterior plaster shell and an attempt is made to localise the level of the lesion by clinical examination The usual surface markings are utilised and it is also helpful to remember that in comminuted fractures the most prominent spinous process is that of the vertebra immediately above the affected disc, while in fracture-dislocations it is that of the vertebra immediately below. Two Michel's skin clips are placed about an inch on each side of the middle line opposite the space between the selected spinous processes, and clips are placed opposite the corresponding spaces above and below. An antero-posterior radiograph is taken the correct level is ascertained, and the incorrectly placed clips are removed The correctly placed clips are left in position in the skin, and serve as a guide during operation.

OPERATIVE TECHNIQUE

The patient is placed on the operating table in the posterior plaster shell, as this position affords easy access to the tibia Two grafts about four-and-a-half inches long and half-an-inch wide are cut from the subcutaneous surface of this bone When the incision has been sutured and a pressure bandage applied the anterior shell is placed in position and the patient is turned face downwards on the table

A central vertical skin incision is made over the tips of the spinous processes of six vertebræ, the centre of the incision being opposite the marking clips Bleeding points are ligatured and the wound is screened with skin towels Two vertical incisions are made through the fascia immediately on the outer side of the spinous processes so that a thin strip of fascia is left intact over these processes and the interspinous ligaments A broad-bladed chisel is used to separate the muscle attachments from the lateral aspects of the spinous processes and the posterior surfaces of the laminæ As the stripping proceeds swabs are firmly packed between the muscles and the exposed bone to prevent hæmorrhage, and by stripping and packing alternately little blood need be lost during this process

When the posterior aspects of the neural arches of the necessary

four vertebræ have been exposed the packs are removed and bleeding points are coagulated with a diathermy The muscles are then retracted with a double bladed self retaining retractor so that the posterior aspects of the laminæ and the articular processes are exposed

In fracture-dislocations reduction must be effected before preparation of the graft beds The interlocked articular processes are carefully identified The ascending articular process on the side to which the spinous processes of the upper segment of the spine are displaced or rotated constitutes the bony block to reduction and can be recognised by the exposed articular cartilage on its postero lateral aspect This process is removed completely after which reduction is effected by gently lifting and rotating the shoulders When reduction is complete pillows are placed beneath the chest to support the spine in moderate extension

The graft bed is prepared by roughening the lateral surfaces of the spinous processes and posterior surfaces of the laminæ with a chisel or file When the superficial cortical bone has been thoroughly broken up the grafts are placed with their medullary surfaces facing the angle made by the laminæ and spinous processes, and all the available bony fragments are packed around them Fixation is secured by suturing the spinal muscles back in position and the skin wound is closed

Strips of half inch felt are placed on each side of the incision to protect it from pressure and bony prominences are padded with adhesive felt The patient is slid upwards on the table the head and shoulders being supported by two assistants until the upper end of the table is in contact with the upper third of the thighs and the anterior shell is removed By raising the head and shoulders above the level of the table the spine can be extended to any required degree and if any lateral angulation is present it is corrected by traction on an encircling loop of bandage placed at the level of the fracture

A plaster jacket is applied extending from the top of the sternum to the symphysis pubis in front, and covering an adequate area of the lumbo dorsal region behind As soon as the plaster is firm the patient is returned to bed one or two pillows being placed behind the posterior concavity of the jacket

POST-OPERATIVE TREATMENT

The immediate post-operative period is not usually complicated by any very severe reactions. Shock is treated by morphia, heat, and, if necessary, by intravenous saline or plasma. Pain is controlled by sedatives. Abdominal distension is relieved by enemata and by

Fig. 44

Fig. 45

Figs. 44 and 45.—The fracture shown in Figs. 37 and 38 four months after combined reduction and arthrodesis. (Although the disorganised intervertebral articulation has been immobilised I think that it would have been an advantage to extend the arthrodesed area to include the intervertebral space below.)

nursing the patient face downwards for an hour or two at regular intervals.

A week after operation graduated spinal exercises are begun in bed, particular attention being paid to developing the extensor musculature. These exercises are carried out regularly and are an essential feature of treatment. The patient is also encouraged to move about freely in bed and to alter position frequently.

Radiographs are taken a few days after operation, and sub

sequently at regular intervals so that any tendency to alteration in the position of the spine may be detected

Weight bearing is started six weeks after operation in comminuted fractures and three to four weeks later in fracture dislocations

Provided the plaster jacket remains effective it is left unchanged until the arthrodesis has consolidated Should it become loose and require changing care is taken to avoid re displacement during this process

Four months after operation the plaster jacket is removed Radiographs are taken and if the grafts are soundly incorporated immobilisation is discontinued (Figs 44 and 45) The patient continues extension exercises for two weeks when further radiographs are taken If these show no change and if no untoward symptoms have followed cessation of immobilisation flexion exercises are commenced and a gradual increase in all activities permitted

With an effective system of spinal exercises and graduated activity such as is practised in an organised Rehabilitation Centre the power and movement of the spine should be normal about two months after immobilisation has been discontinued although as is to be expected the rate of recovery varies somewhat with the age and general condition of the patient

CHAPTER VII

FRACTURES OF THE CLAVICLE

ALTHOUGH reduction is frequently imperfect, and immobilisation far from mechanically effective, fractures of the clavicle almost always unite rapidly

The results of conservative treatment of these injuries are so good that operative measures are seldom necessary.

INDICATIONS FOR BONE-GRAFTING

1. Fracture of the shaft of the clavicle with established non-union. —Occasionally a fracture of the shaft of the clavicle fails to unite

FIG 46
A six-months-old un-united fracture of the clavicle

The fracture surfaces are separated by fibrous tissue which becomes organised, and sclerosis of the bone-ends follows (Fig 46) This *may* occur in simple fractures, possibly as the result of interposition of muscle between the bone-ends. More commonly non-union follows the removal of too much bone at the initial debridement of compound comminuted fractures Strangely enough, *non-union* is not uncommonly seen after division of the clavicle in the surgical exposure of the brachial plexus or axilla

Once non union has become established immobilisation alone is of no value and bone grafting of the fracture is indicated

FRACTURES IN WHICH BONE-GRAFTING IS NOT INDICATED

1 Un-united fractures of the outer end of the clavicle—Not uncommonly fractures of the extreme outer end of the shaft of the clavicle fail to unite It is unnecessary to bone graft these fractures in an attempt to produce union as symptoms are completely relieved by the much simpler procedure of excising the small outer fragment

PRE-OPERATIVE TREATMENT

As a result of previous immobilisation clavicular fractures in which bone grafting is indicated are usually associated with considerable limitation of shoulder movement If immobilisation has been effected by a technique entailing strapping the arm forearm and hand to the body there may also be stiffness of the elbow wrist and fingers

Permanent disability particularly in older patients is much more likely to result from stiffness of these joints than from non union of the fracture

Before operation for non union is contemplated all forms of immobilisation should be discarded and active exercises of the stiff joints instituted These should be continued until a full range of finger wrist and elbow movement and active abduction of the shoulder to more than 90 degrees are regained It is not usually possible to achieve a full range of shoulder movement in the presence of an un united fracture of the clavicle but if active abduction to more than a right angle is present before operation there is a reasonable prospect of regaining full movement after union has been secured

Skin preparation is carried out in the usual way, the area of skin prepared including the neck, shoulder and axilla

METHOD OF GRAFTING

Various techniques for grafting have been described A *small* graft may be inlaid across the fracture on the subcutaneous surface of the clavicle or onlay grafts may be applied to the subcutaneous posterior or antero-inferior surfaces of the bone

Since it is possible to cut only a comparatively small rectangular

slot in the clavicle the size of the inlay graft which can be used is strictly limited. Such grafts are very liable to subsequent fracture and do not produce adequate internal fixation.

Onlay grafts placed on the most easily accessible that is, the subcutaneous, surface project beneath the skin and produce an unsightly prominence The posterior surface is difficult of access, grafts placed on this surface are not easy to fix, and may subsequently produce symptoms by pressure on underlying structures.

A B

Fig. 47

The graft fixed in position with screws (A), as indicated in diagram (B)

The simplest and most effective technique consists in placing an onlay graft on the antero-inferior aspect of the clavicle (Fig 47) Although this surface of the bone is narrow, grafts so placed do not project beneath the skin and can be fixed firmly with screws. By cutting a suitably-shaped bed it is possible to effect stable fixation with a stout graft by this technique.

TECHNIQUE OF OPERATION

The clavicle is most accessible with the patient supine and resting on a small sandbag placed between the shoulders, the head being turned away from the affected side

The skin incision is made immediately above the clavicle, so that the subsequent scar may lie in the supra-clavicular hollow where it is less obvious, and extends for about two-thirds of the length of the bone The skin and platysma muscle are divided, bleeding points are ligatured, and the wound is screened with skin towels.

The periosteum is incised along the centre of the subcutaneous

surface of the clavicle, and is stripped from the anterior and antero-inferior aspects of the bone Stripping is continued in the region of the fracture until the bone-ends are exposed, care being taken to avoid tearing the periosteum where it is adherent to the fracture line

When the bone-ends are exposed they are cleared of fibrous tissue and "freshened" It is essential to avoid removing the bone too

FIG 48
The fracture shown in Fig 40 four months after grafting

freely during the "freshening" process or it will be found impossible to bring the fractured surfaces into apposition

The fracture is reduced and the graft bed is prepared on the antero inferior surface of the clavicle with a chisel A tibial graft, about two and a half inches long and rather less than half an inch wide is placed in position and held with bone clamps The graft is fixed to the clavicle with screws one screw being placed in each fragment (Fig 47) and the bone chips are packed around the fracture and graft or used to fill in any defects which may be present

The periosteum is sutured the platysma is repaired and the skin incision is closed

POST-OPERATIVE TREATMENT

Immobilisation of the fractured clavicle is notoriously difficult. The number of methods described is certain evidence that no single one is entirely satisfactory.

A plaster shoulder spica is the most effective method after bone-grafting The body-piece of the spica is applied forty-eight hours before operation and it is completed when dressings have been applied to the wound, the arm-piece being lightly padded with wool

The arm is immobilised with the shoulder in 45 degrees of abduction, of flexion, and of internal rotation, the elbow being in 90 degrees flexion

The spica is retained until the fracture is consolidated (Fig 48), being changed when necessary.

Union of the fracture is to be expected in from eight to twelve weeks; although, if bone loss has occurred, a period of some months' immobilisation may be necessary to permit complete consolidation

CHAPTER VIII

FRACTURES OF THE HUMERUS

A COMPARATIVELY small proportion of fractures of the humerus require operative treatment

FRACTURES IN WHICH BONE-GRAFTING IS INDICATED

1 **Fractures of the humeral shaft with delayed union or established non-union** —Most types of fracture of the humeral shaft unite

Fig 49 Fig 50

Figs 49 and 50 —A transverse fracture of the humeral shaft after sixteen weeks immobilisation. There was no clinical or X ray evidence of union.

rapidly in spite of imperfect reduction or incompletely effective immobilisation In transverse fractures about the junction of the middle and lower thirds, however union may be long delayed (Figs 49 and 50) This is probably due to the cutting off of the blood supply to the lower fragment and if established non union is

to be avoided, such fractures must be effectively immobilised for very long periods Union can usually be secured by conservative treatment alone, but this entails immobilisation in a complete shoulder spica for from six to twelve months. This period can be greatly reduced by timely bone-grafting in suitable cases (Figs. 51 and 52) and if a transverse fracture shows no clinical or radiological

FIG 51

FIG 52

FIGS 51 and 52 —The fracture shown in Figs 49 and 50 three months after bone-grafting

evidence of union after three months effective immobilisation in a shoulder spica grafting is indicated

Grafting is also indicated in all such fractures in which non-union as shown by sclerosis of the bone-ends has become established (Figs. 53 and 54)

Union is also commonly delayed in fractures of the extreme lower end of the humeral shaft This type of fracture about an inch above the site of the supracondylar fracture, is uncommon and is often the result of a gunshot wound An un-united fracture in this region is usually associated with damage and stiffness of the elbow joint and constitutes a very severe disability (Figs 55 and 56). The function of the arm is so poor that it is justifiable to secure union

Fig 53

Fig 54

Figs 53 and 54.—A two years-old fracture of the humeral shaft in which non union is established. Four months after injury this fracture was grafted an intramedullary graft being used The remains of this graft can still be seen in the medullary cavity of both fragments.

Fig 55

Fig 56

Figs 55 and 56.—An un united fracture of the lower end of the humeral shaft following a gunshot wound

by bone-grafting (Figs 57 and 58), even if there is little prospect of restoring more than a few degrees of elbow movement

Fig 57

Fig 58

Figs 57 and 58—The fracture shown in Figs 55 and 56 four months after bone-grafting

FRACTURES IN WHICH BONE-GRAFTING IS NOT INDICATED

1. After open reduction of fractures of the neck of the humerus.—Open reduction is occasionally necessary in fractures of the neck of the humerus (Fig. 59) Once secured, reduction is stable and, as Pulvertaft [1] has pointed out, no form of internal fixation is necessary (Fig. 60) Various techniques for bone-grafting such fractures have been described, the use of an intramedullary peg being the method most commonly employed. Such procedures are unnecessary and, in the case of intramedullary grafts, harmful

2. Fractures of the humeral neck with established non-union.—Established non-union of fractures of the humeral neck is extremely uncommon, and is usually the result of too early mobilisation of such fractures Treatment consists of exposure of the fracture thorough removal of all fibrous tissue and sclerotic bone, reduction and impaction of the bone-ends, and subsequent immobilisation in an

FIG 59

FIG 60

FIG 59.—A six weeks-old fracture of the humeral neck in which attempts at reduction by manipulation had failed

FIG 60.—The fracture shown in Fig 59 ten weeks after open reduction without internal fixation.

FIG 61

FIG 62

FIGS 61 and 62.—An oblique fracture of the humeral shaft with a loose butterfly fragment.

abduction spica. The results of treatment on these lines are entirely satisfactory and bone-grafting is unnecessary.

3. Spiral fractures of the humeral shaft.—In spiral fractures of the humeral shaft, especially those in which there are loose "butterfly" fragments, accurate manipulative reduction may be impossible owing to the sharp ends of the bony fragments being

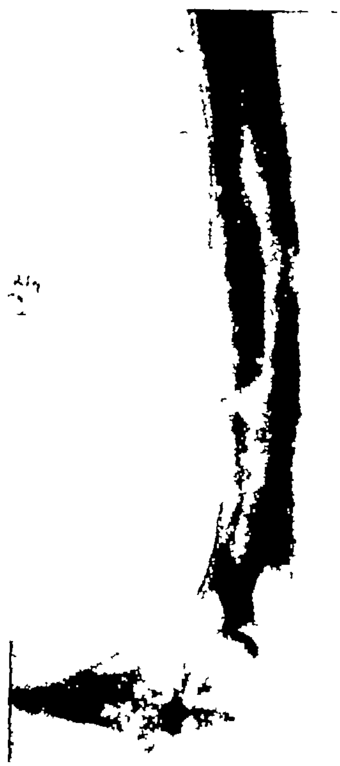


FIG 63

FIG 64

FIGS 63 and 64 —The fracture shown in Figs 61 and 62 eight weeks after injury The callus formation is obvious

embedded in adjacent muscles (Figs. 61 and 62) Such fractures unite readily, however, and operative reduction and bone-grafting is unnecessary (Figs. 63 and 64)

PRINCIPLES OF OPERATION

In any fracture in which the blood supply to one fragment has been cut off union is slow even after bone-grafting, and inadequate grafting may fail to produce union

Completely effective internal fixation and a large graft are essential in this type of fracture of the humeral shaft. It is extremely difficult to produce absolute immobilisation of such fractures by

external fixation alone The body piece of the best shoulder spica tends to become loose and permit a little movement of the shoulder girdle Consequently strains are transmitted to the fracture and some movement between the fragments tends to take place If internal fixation is inadequate movement occurs and union is delayed and if fixation depends on a small graft these strains may produce fracture or absorption of the graft at the fracture line These complications are prevented by the use of a large onlay graft which is firmly fixed on the anterior aspect of the humeral shaft by screws (Figs 51 and 52) Before reduction the bone ends are completely cleared of all fibrous tissue and sclerosed bone and bone fragments are packed around the fracture when the graft is in position

This technique is suitable for all fractures except those of the extreme lower end of the humeral shaft Here the fracture cannot easily be exposed by the anterior approach, and it is more satisfactory to employ onlay grafts applied to the posterior aspect of the bone (Figs 57 and 58) Owing to the shortness of the lower humeral fragment much smaller grafts are used but since these fractures are much more easily immobilised by external fixation the grafts are not subsequently subjected to any very severe strain and are quite adequate It is often possible to use two grafts one fixed to the posterior aspect of each epicondyle for these fractures

PRE-OPERATIVE TREATMENT

Fractures which have already been immobilised for a very long period are associated with considerable stiffness of the elbow and shoulder and with trophic changes of the skin Before operation it is usually safe to discard all forms of fixation except short medial and lateral plaster slabs for a short period The arm is supported in a sling and active movements of the elbow and shoulder are practised

The skin of the arm usually returns to normal in a week or ten days when the usual skin preparation can be commenced

TECHNIQUE OF OPERATION

1 **Fractures of the humeral shaft**—A graft between four and a half and six inches long and an inch to an inch and a-quarter wide is cut from the subcutaneous surface of the tibia prepared in the usual way and stored in saline

The shaft of the humerus is best exposed by the anterior approach described by Henry [2] No tourniquet is used, as it is impossible to obtain an adequate exposure with a tourniquet in position.

The forearm and arm are covered with stockinet in the usual way, the arm is slightly abducted and placed on a narrow table. The elbow is extended as fully as possible, the forearm being controlled by an assistant.

The skin incision commences in the delto-pectoral groove at the level of the lower border of the anterior axillary wall, follows this groove to the insertion of the deltoid, continues downward following the outer edge of the biceps, to the centre of the antecubital fossa, and ends by extending a few inches down the mid-line of the flexor aspect of the forearm This incision follows the course of the cephalic vein and several branches of this vessel require ligation.

The deep fascia is divided in the line of the skin incision and the medial border of the deltoid and the lateral border of the biceps are identified The biceps is retracted medially to expose the insertion of the deltoid and the origin of the brachialis extending upwards in front of and behind this insertion

The humerus is cut down upon along the medial border of the deltoid and this cut is extended downwards, dividing the brachialis below the deltoid insertion The outer fourth and inner three-fourths of the brachialis are separated by this incision, which is carried down to within an inch of the level of the epicondyles, completely dividing the muscle and periosteum Bleeding points are ligatured the elbow is flexed, and the humerus is exposed in the depths of the wound by retraction.

The periosteum and brachialis attachment are stripped from the humerus with an elevator Stripping is commenced immediately above and below the fracture and is continued upward and downward until an adequate amount of the bone is exposed

The musculo-spiral nerve is not seen during this exposure being carried outward and protected from the elevator by the outer strip of the brachialis. This nerve can be exposed, if required, where it lies behind the brachialis an inch below the insertion of the deltoid

Bone spikes slipped between the bone and periosteum act as retractors and when the elbow is flexed the wound can be widely opened up, completely exposing the fracture.

All fibrous tissue and sclerotic bone are removed from the bone-

ends and the fracture is reduced The graft bed is prepared on the anterior aspect of the humerus with a chisel the graft is placed in position and is held with clamps (Fig 65) The graft is then fixed in position with screws and bone fragments are packed around the fracture

The periosteum and brachialis are approximated over the graft with interrupted sutures the deep fascia is sutured and the skin wound is closed

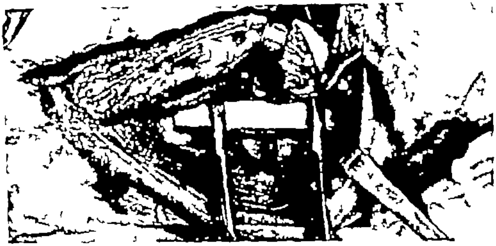


FIG 65

The graft held in position with clamps prior to fixation with screws.

The arm and forearm are immobilised in a well padded plaster extending from the shoulder to the wrist, the elbow being in about 90 degrees of flexion and the forearm in mid position

2 **Fractures of the lower end of the humeral shaft.**—The patient is placed face downwards on the operating table and the arm is supported on a separate table with the elbow as fully extended as possible No tourniquet is used

The incision extends upwards from the tip of the olecranon process for about six inches

The first step in operation is to identify and retract the ulnar nerve The skin and subcutaneous tissue are dissected off the deep fascia on the medial side of the incision until the nerve is exposed as it lies behind the medial epicondyle The nerve is mobilised and gently retracted medialwards

The triceps muscle is then divided in the line of the skin incision This muscle is retracted the periosteum is incised in the same line and is stripped from the bone, exposing the fracture and the

little place in the treatment of post traumatic joint stiffness and massage and passive movement are actively harmful particularly in the case of the elbow

It must be remembered that delay in the later stages of recovery is often more apparent than real A twenty per cent decrease in limitation of movement at this stage may only be represented by an increase of two or three degrees in the range of movement while in the early stages a similar improvement is represented by an increase in range of twenty or thirty degrees This must be pointed out to the patient who is encouraged to persist assiduously with the regular active exercises which are the only effective means of restoring joint movement

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2 Henry Arnold K., *Exposures of Long Bones and Other Surgical Methods* pp 3-8 J Wright & Son, Bristol, 1927

CHAPTER IX

FRACTURES OF THE RADIUS

MOST fractures of the radius occur close to the upper or lower extremities of the bone, and bone-grafting has no place in the treatment of these injuries. Grafting is, however, indicated in some types of fracture of the radial shaft

INDICATIONS FOR BONE-GRAFTING

1. Fractures at the junction of the middle and lower thirds of the shaft, with subluxation of the inferior radio-ulnar joint.—The most

FIG 66

FIG 67

A fracture of the radial shaft with a gross dislocation of the inferior radio-ulnar joint

common site of fracture of the radial shaft is the junction of the middle and lower thirds Provided the ulna remains intact overlap of the bone-ends can occur only if there is an associated dislocation of the inferior radio-ulnar joint, and this dislocation is almost invariably present (Figs 66, 67, 68, and 69) The triangular fibro-cartilage is avulsed, with or without a fracture of the ulnar styloid process, and the whole hand and carpus is displaced upwards with the lower fragment of the radius Accurate reduction of the fracture

can be secured only in association with complete reduction of the dislocation and reductions of both fracture and dislocation are necessary if subsequent disability is to be avoided

The results of conservative treatment are unsatisfactory in a high proportion of cases These fractures are very unstable and although adequate reduction can usually be secured by manipulation provided this is carried out within a few days of injury it is often impossible to maintain reduction by any form of external fixation

FIG 68

FIG 69

A fracture of the radial shaft with dislocation of the inferior radio-ulnar joint. The displacement may seem trivial but unless reduction is accurate and the joint is restored to normal subsequent disability is inevitable

In transverse fractures it is justifiable to attempt treatment by simple manipulation and subsequent immobilisation in plaster Reduction of both fracture and dislocation must be accurate and frequent radiographs are subsequently necessary to ensure detection of re-displacement without delay Should re displacement occur open reduction and internal fixation is indicated

Immediate operative treatment is indicated in oblique or comminuted fractures

The essential features of adequate operative treatment are accurate reduction and mechanically stable internal fixation Fixation by means of transfixation screws is not usually adequate and although good results can be obtained using vitallium plates

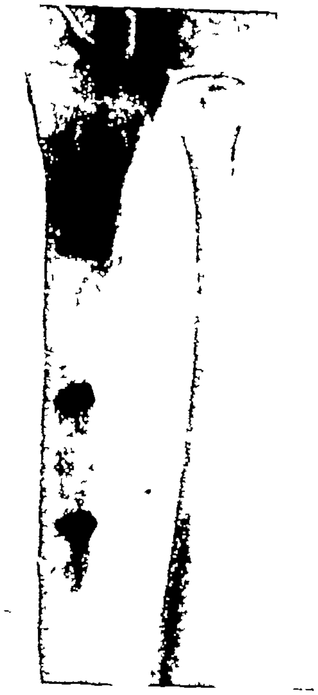

Fig 70

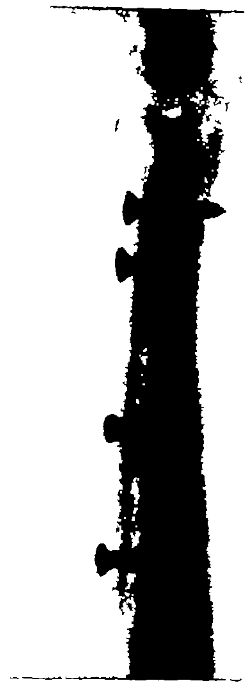

Fig 71

The fracture shown in Figs 68 and 69 six months after open reduction and grafting

Fig 72

Fig 73

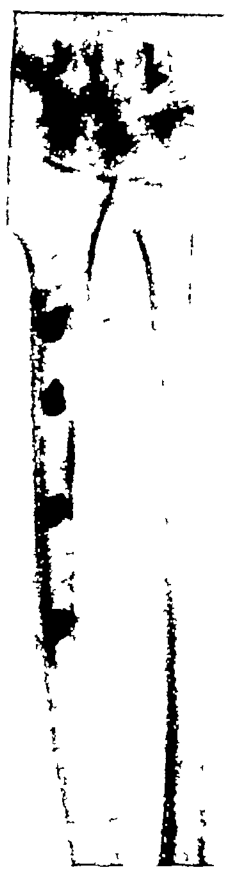

Fig 74

Fig 75

Figs 72 and 73 —A two-months-old fracture of the radial shaft The fracture has not been accurately reduced and the inferior radio-ulnar joint remains dislocated This position should not have been accepted

Figs. 74 and 75 —The fracture shown in Figs 72 and 73 after open reduction and grafting

and screws I consider that the most satisfactory method is to employ a stout onlay graft fixed in position with screws Effective grafting produces stable fixation and ensures rapid union of the fracture (Figs 70 and 71, 74 and 75)

These fractures may not present themselves for treatment until some time after injury (Figs 72 and 73) In the later stages a persistent dislocation may be associated with union in malposition or established non union of the radial fracture If the dislocation has been present for some months soft tissue contraction precludes either operative or manipulative reduction and excision of the lower end of the ulna is necessary This is combined with grafting of un united fractures of the radius or osteotomy reduction and grafting of fractures which have united in gross malposition

2 **Fractures of the radial shaft with interposed soft tissues** — Isolated fractures of the radial shaft with lateral displacement of the bone-ends may occur as a result of direct violence The inferior radio-ulnar joint is not dislocated and overlap does *not* occur but it may be impossible to reduce the lateral displacement by manipula tion owing to interposition of muscle between the bone-ends (Figs 76 and 77) This is particularly liable to occur in fractures in the region of the pronator teres insertion Unless the fractured surfaces are brought into apposition delayed union or non union is inevitable

Should manipulation fail to produce accurate reduction in this type of fracture open reduction is indicated and internal fixation should be secured by bone-grafting (Figs 78 and 79)

PRINCIPLES OF OPERATION

The onlay technique is the simplest and by far the most effective method of grafting the forearm bones

After reduction of the fracture the graft bed is prepared on the anterior surface of the radius and a tibial graft is fixed in position with screws

Fractures associated with an inferior radio ulnar dislocation are extremely unstable and effective internal fixation must be ensured by using a long graft fixed with four screws (Figs 70 and 71 74 and 75) In other fractures a smaller graft, held by two screws is quite adequate (Figs 78 and 79)

Soft tissue contraction may make it impossible to secure complete reduction of an inferior radio-ulnar dislocation which has been

present for some months In these circumstances grafting of the radial fracture should be combined with excision of the lower end of the ulna. I do not believe that these procedures should be carried out at the same time, if this can be avoided, as I consider that a prolonged period of immobilisation, such as is necessary to permit

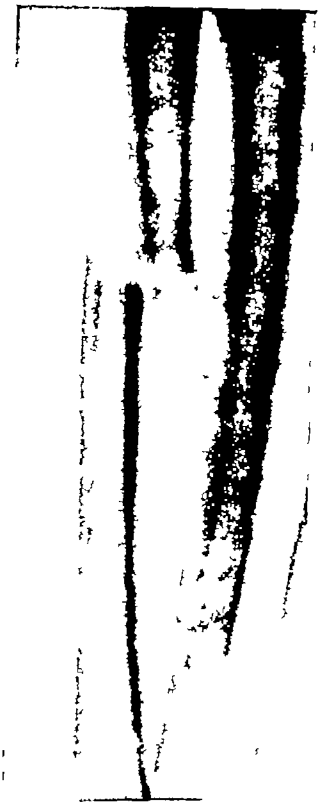

FIG 76

FIG 77

FIG 78

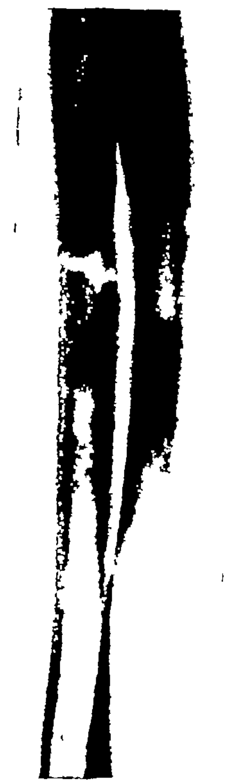

FIG 79

FIGS 76 and 77 —A fracture of the radial shaft with interposed soft tissue Repeated manipulation had failed to secure accurate reduction

FIGS 78 and 79 —The fracture shown in Figs 76 and 77 after open reduction and grafting A small inlay graft held with two screws has been used, and as this type of fracture is not very liable to become re-displaced once it has been reduced this technique is adequate in the circumstances

consolidation of the radial fracture, decreases the prospect of regaining a full range of pronation and supination after excision of the lower end of the ulna

The radial fracture should be grafted first and, if subsequent radiographs show that the associated dislocation has not been completely reduced, the lower end of the ulna is excised when it is judged that only a further three or four weeks' immobilisation is necessary to permit complete consolidation of this fracture Occasionally, however, in very old fractures with gross displacement it may be

impossible to align the radial fragments without first excising the lower end of the ulna and in such cases there is no option but to combine these procedures

PRE-OPERATIVE TREATMENT

In recent fractures operation can be carried out as soon as the immediate effects of injury have subsided The usual skin preparation is necessary and the patient is instructed in finger and shoulder exercises before operation

Old fractures, which have previously been immobilised are usually associated with considerable joint stiffness All immobilisation can be discontinued for a short period without danger the arm is supported in a sling and active exercises are carried out particular attention being paid to regaining elbow movement

TECHNIQUE OF OPERATION

A tourniquet is used and the arm is abducted and supported on a small table Sterile stockinet is applied in the usual way the elbow is extended and the forearm is supinated

Henry s[1] method of approach is used but is slightly modified so that the anterior rather than the postero-lateral aspect of the radius is exposed

The skin incision commences in the antecubital fossa, immediately on the outer side of the biceps tendon and extends downward over the centre of the outer aspect of the radius to the lower end of the bone

The deep fascia is divided in the same line and the medial edge of the brachio radialis is identified at the upper end of the incision and followed downwards until the muscle can be mobilised and retracted outwards This exposes the radial artery and the superficial branch of the radial nerve lying from above downward on the insertion of the biceps tendon the insertion of the supinator brevis the insertion of the pronator teres and the flexor longus pollicis The nerve lies on the outer side of the vessels from which it can easily be separated and retracted outwards with the brachio radialis The artery is gently retracted inwards

The radius is exposed from above downwards The bone is cut down on immediately below and to the outer side of the insertion of the biceps tendon the periosteum is divided and stripped off the antero-lateral aspect of the radial shaft In this way the supinator

brevis is detached subperiosteally and is thrown outward, carrying the deep branch of the radial nerve. As this muscle is detached the periosteal incision is continued downward and slightly outward, in the plane between the supinator brevis attachment and the origins of the flexor sublimus digitorum and flexor pollicis longus When the lower limit of the supinator brevis is reached the incision is continued downward on the antero-lateral aspect of the radius and the periosteum is stripped off the anterior aspect of the bone, so that the pronator teres, the flexor sublimus digitorum and flexor pollicis longus and, finally, the pronator quadratus are detached medially.

When the lower end of the radius is reached bone spikes are slipped between the periosteum and the bone, the elbow is flexed and the whole wound can be opened up, completely exposing the anterior aspect of the radius

Such a complete exposure is not always necessary and the approach is restricted accordingly. It is a mistake to attempt to restrict the exposure unduly, however, as this adds greatly to the difficulties of operation.

The bone-ends are cleared of fibrous tissue, and the fracture is reduced Strong traction is necessary to effect reduction of fractures associated with an inferior radio-ulnar dislocation, and when the bone-ends are brought into apposition any anterior or posterior angulation must be completely corrected.

When the reduction has been effected the bone is held with bone-holding forceps while the graft bed is prepared by removing, with a chisel, the outer cortical layers of the radius for a suitable distance above and below the fracture

A graft, cut from the subcutaneous surface of the tibia, and about three-and-a-half-inches long and half-an-inch wide, is used This graft is placed in position, held with bone clamps, and fixed with screws

The periosteum and muscle attachments are approximated with interrupted sutures over the graft and radius, and the skin incision is closed

The arm is immobilised in a well-padded plaster from the meta-carpal heads to the upper third of the humerus The plaster is first applied below the tourniquet and when this part has set the tourniquet is removed and the plaster is completed

POST-OPERATIVE TREATMENT

Post operative swelling is not usually very marked and provided adequate padding has been used it is not often necessary to bi valve the plaster

Finger and shoulder exercises are continued immediately after operation When a full range of finger movement is possible exercises against resistance are instituted using a sponge rubber " grip " In this way wasting of the forearm muscles is prevented

Two weeks after operation the padded plaster is taken off skin stitches are removed and an unpadded plaster is applied from the upper third of the humerus to the metacarpal heads Immobilisation in this type of plaster is continued until the fracture has united and the graft is soundly incorporated This is to be expected in from eight to fourteen weeks

When a long standing radio ulnar dislocation which has not been adequately reduced by operation on the radius is present the lower end of the ulna must be excised About eight or ten weeks after operation when radiographs show that the fracture has almost completely consolidated the plaster is bi valved to allow skin preparation for forty eight hours Between dressings immobilisation is continued by fixing the bi valved plaster firmly in position with a bandage

No tourniquet is used and a short skin incision is made directly over the lower end of the ulnar shaft which is divided subperiosteally The head of the ulna is freed by sharp dissection care being taken to avoid damage to the triangular ligament and is removed The skin incision is sutured and an unpadded plaster is reapplied This plaster is discarded three or four weeks later when consolidation of the radial fracture is complete

When the plaster has been removed active exercises to restore elbow and wrist movement, and rotation of the forearm are commenced A few weeks treatment at an organised Rehabilitation Centre is of great value at this stage

The results of treatment by bone grafting in these types of fractures of the radius are very satisfactory Full function of the arm with no disability is to be expected about two months after immobilisation has been discontinued

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[1] Henry Arnold K. *Exposures of Long Bones and Other Surgical Methods* pp 9–12 J Wright & Son, 1927

CHAPTER X

FRACTURES OF THE ULNA

THE ulna is subcutaneous and comparatively exposed For this reason fractures of the shaft from direct violence are somewhat more common than is the case with the radius. Fractures of the ulnar shaft also occur in association with dislocation of the head of the radius In certain circumstances bone-grafting is indicated in the treatment of these injuries

INDICATIONS FOR BONE-GRAFTING

1. In fracture of the ulnar shaft associated with dislocation of the head of the radius.—Fractures in the region of the junction of the middle and upper thirds of the ulnar shaft occur in association with an anterior or posterior dislocation of the head of the radius (Figs 80 and 81) The line of displacement is through the radio-humeral joint, the radio-ulnar joint, and the fracture, and the radius and lower fragment of the ulna are displaced in relation to the humerus and upper ulnar fragment

Accurate reduction of both fracture and dislocation is essential. Reduction may be secured by early manipulation and maintained by external fixation, but treatment on these lines is not always successful

If accurate reduction cannot be secured by manipulation, or if re-displacement in plaster occurs, open reduction and internal fixation is indicated Even in recent fractures grafting is the most generally satisfactory method of securing fixation of the ulna

These fractures are frequently seen some time after injury. At this stage an un-united or, occasionally, a mal-united fracture of the ulna is associated with a persistent dislocation of the head of the radius Treatment of the dislocation, either by open reduction or excision of the head of the radius, should be combined with open reduction and grafting of the ulnar fracture.

2. Delayed union or non-union of fractures of the shaft of the ulna.—Occasionally in fractures of the shaft of the ulna union may be long delayed (Figs 82 and 83). This is usually due to inadequate

immobilisation and is particularly liable to occur in fractures in the region of the junction of the middle and lower thirds of the shaft, which are subjected to strong shearing strain if inadequate immobilisation permits rotation of the forearm

Provided non union has not become established these fractures

Fig 80 Fig 81

An un-united fracture of the ulnar shaft with an anterior dislocation of the radial head The elbow is shown in 90-degrees flexion (Fig 80) and in extension (Fig 81).

will unite if adequate immobilisation is effected and maintained The period of treatment necessary to secure union can be considerably reduced however by bone-grafting in suitable cases (Figs 84 and 85)

3 Fractures of the shaft with displacement between the bone-ends—Lateral displacement between the bone-ends may occur in isolated fractures of the ulnar shaft (Figs 86 and 87) If this displacement cannot be corrected by manipulation open reduction and fixation by means of a small onlay graft is indicated (Figs 88 and 89)

Fig 82

Fig 83

Fig 84

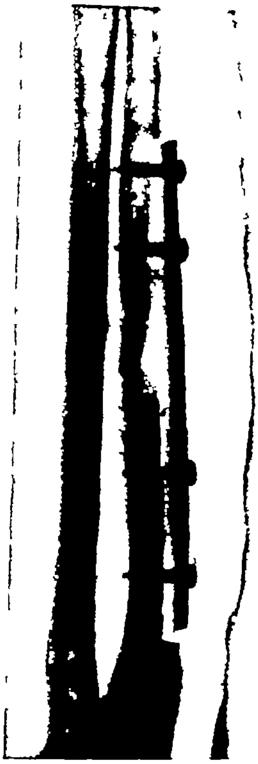

Fig 85

Figs 82 and 83 —A five-months-old fracture of the ulna in which union has been delayed because of bone loss

Figs 84 and 85 —The fracture shown in Figs 82 and 83 after bone-grafting

Fig 86

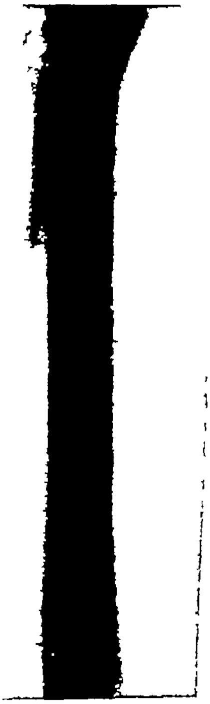

Fig 87

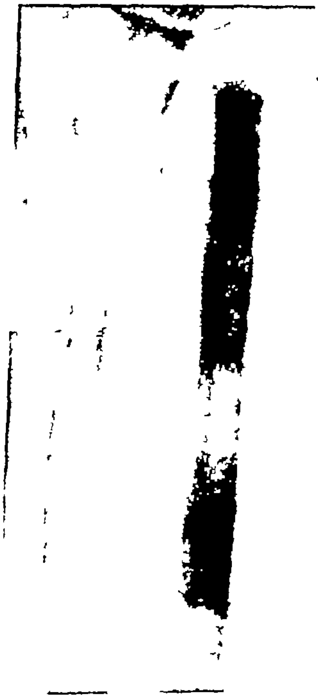

Fig 88

Fig 89

Figs 86 and 87 —A four-weeks-old fracture of the ulna with persistent displacement which could not be corrected by manipulation

Figs 88 and 89 —The fracture shown in Figs 86 and 87 after open reduction and grafting

FRACTURES IN WHICH BONE-GRAFTING IS NOT INDICATED

1 **Fractures of the olecranon** —Bone grafting has no place in the treatment of fractures of the olecranon Although operation is usually necessary when displacement at the fracture has occurred the essential requirements are repair of the extensor mechanism by restoring the attachment of the triceps to the ulna and avoidance of any persistent irregularity of the humeral articular surface of the ulna Both these requirements are fulfilled by excision of the olecranon fragment and repair of the triceps and this simple procedure is only contra indicated in olecranon fractures which have been associated with an anterior dislocation of the elbow Even when reduction and internal fixation of the fracture is necessary the technical difficulties associated with securing really adequate fixation by bone-grafting make this procedure inadvisable

PRINCIPLES OF OPERATION

The delay in union so often seen in fractures of the ulna is due to the difficulty in protecting these fractures completely from mechanical stresses by external fixation It is therefore essential to secure mechanically stable internal fixation if rapid union is to be expected after bone grafting This is particularly important in fractures associated with a dislocation of the head of the radius These fractures are extremely unstable and being near the elbow joint, difficult to immobilise It has even been suggested that grafting should be combined with plating in such fractures

Completely adequate fixation can be secured however by a long onlay graft fixed with screws if this technique is properly employed

The ulna is roughly triangular in shape having an internal surface and anterior and posterior surfaces converging to meet at the inter osseous border The graft bed is prepared on the posterior surface and the graft is fixed in position with four screws (Figs 84 and 85 88 and 89)

There are several alternative methods of dealing with an associated dislocation of the head of the radius

In recent injuries this dislocation can usually be reduced by manipulation when the ulnar fracture is exposed and some surgeons prefer to rely on external fixation together with internal fixation of the ulnar fracture to prevent re dislocation I consider it more

satisfactory to combine reduction with a reconstruction of the orbicular ligament, using a fascial strip threaded through drill holes in the ulna It must be pointed out, however, that many authorities consider that early reconstruction of the orbicular ligament in conjunction with reduction and internal fixation of the ulnar fracture is unwise, because of the danger of subsequent radio-ulnar ankylosis due to post-operative ossification.

In old injuries grafting of the ulnar fracture and excision of the head of the radius is a most satisfactory procedure in adults, although in children and adolescents open reduction of the dislocation and reconstruction of the orbicular ligament is necessary, as removal of the head of a still growing radius may cause subsequent inequality in length between the forearm bones sufficient to produce disorganisation of the inferior radio-ulnar joint

PRE-OPERATIVE TREATMENT

In recent fractures skin preparation is started as soon as the immediate effects of injury have subsided, and operation is carried out a few days later

In old fractures which have previously been immobilised the usual preliminary period of active exercises without any form of immobilisation is indicated.

TECHNIQUE OF OPERATION

When the tourniquet is in position the patient is turned face downwards on the operating table Sterile stockinet is applied and the arm is supported on a small table with the elbow fully extended In this position the whole ulna is easily accessible.

The skin incision is made over the posterior border of the bone and extends for a suitable distance above and below the fracture This incision can be extended upward and slightly laterally if necessary, to afford access to the head of the radius

When the skin and subcutaneous tissue have been divided the posterior border of the ulna is cut down on in the plane between the origins of the flexor and extensor carpi ulnaris The periosteum is divided in the line of the skin incision and is stripped from the ulna to expose the bone-ends and posterior surface for a suitable distance above and below the fracture

If a dislocation of the upper end of the radius is present this must

be dealt with by manipulative or operative reduction or by excision of the radial head. In old injuries it is often impossible to produce adequate reduction of the ulnar fracture until the dislocation has been reduced.

A tibial graft about three and a half inches long and just over half an inch wide is used. When the bone ends are cleared of fibrous tissue and the fracture reduced the graft bed is prepared on the posterior aspect of the ulna with a chisel and the graft is placed in position and fixed with screws. Bone fragments are packed around the fracture and the periosteum and muscle origins are approximated over the graft with interrupted sutures.

The skin is closed and the arm is immobilised in a padded plaster extending from the upper third of the humerus to the metacarpal heads. In fractures associated with a superior radio ulnar dislocation pads of adhesive felt are placed over the anterior and lateral aspects of the radial head and the plaster is moulded so as to exert sufficiently firm pressure on these pads to prevent re-dislocation.

POST-OPERATIVE TREATMENT

Post-operative swelling is not marked and it is rarely necessary to bivalve the padded plaster.

When a dislocation has been present radiographs are necessary at least every seven days for six weeks to ensure that displacement of the radial head has not recurred.

Two weeks after operation an unpadded plaster is applied after the skin sutures have been removed.

The usual finger and shoulder exercises are carried out and immobilisation is continued until the fracture has consolidated. This is usually to be expected in from ten to sixteen weeks although occasionally an ulnar fracture appears to be very indolent even after grafting and immobilisation for a considerably longer period is necessary.

When union is complete the plaster is removed and active exercises of the elbow shoulder and wrist are commenced. Particular attention is paid to regaining elbow movement and a period of treatment at a Rehabilitation Centre is of great value.

In a high percentage of patients full function of the arm is regained although some months activity and persistent exercise may be necessary to restore a full range of elbow movement.

CHAPTER XI

FRACTURES OF THE RADIUS AND ULNA

FRACTURES of both bones of the forearm have certain characteristic features. It is difficult to produce accurate reduction by manipulation, and even if early reduction is secured it is difficult to prevent re-displacement by external fixation. Union in malposition is associated with material disability, either angulation or a rotational displacement disturbs the function of the superior and inferior radio-ulnar joints. Unless immobilisation is completely effective union of the fractures is seriously delayed and may never occur.

Bone-grafting is often a most valuable measure in the treatment of these fractures.

INDICATIONS FOR BONE-GRAFTING

1. After open reduction of fractures of the radius and ulna.—Open reduction is often necessary in fractures of both forearm bones Operation is indicated in recent fractures if accurate reduction cannot be secured by manipulations (Figs 90 and 91) or if re-displacement occurs in spite of external fixation (Figs 92 and 93)

Open reduction is also indicated at any stage during treatment if angulation between the fragments or a rotational deformity of the forearm is present The dysfunction associated with these deformities is so severe that it is worth while to secure reduction even though it entails an operation and a considerable prolongation of treatment

2. In delayed union or established non-union.—If union is delayed the period of immobilisation necessary may be considerably reduced by timely bone-grafting. Grafting is also indicated if non-union of one or both fractures becomes established

3. After osteotomy and correction of deformity in old fractures.—Treatment may be necessary in fractures which have been allowed to unite in malposition (Figs. 94 and 95) Provided secondary changes in the radio-ulnar joints have not become established

Fig 90

Fig 91

Fig 92

Fig 93

Figs 90 and 91 — A fracture of the radius and ulna in which adequate reduction could not be secured by manipulation.

Figs 92 and 93 — A two-weeks-old fracture of the radius and ulna in which redisplacement occurred in plaster after an initial adequate reduction (Fig 92) This was treated by operation and it was found possible to secure reduction and stable fixation by exposing and grafting the radius onlv (Fig 93)

Fig 94

Fig 95

Fig 96

Fig 97

Figs 94 and 95 —A six months-old fracture of the radius and ulna Reduction is not adequate, and the fracture of the ulna has not united.

Figs 96 and 97 —The fracture shown in Figs. 94 and 95 six months after open reduction and grafting of both bone

osteotomy at the fracture sites and correction of the deformity is indicated, and should be combined with bone-grafting (Figs. 96 and 97)

4. After re-fracture.—Re-fracture of the radius and ulna is not uncommon and is due to too early cessation of immobilisation If complete re-fracture with displacement has occurred the most rapid way of securing firm union is by open reduction and bone-grafting

PRINCIPLES OF OPERATION

The aim of operation is to restore normal relationship between the upper and lower segments of the forearm, and to obviate as far as possible the possibility of subsequent re-displacement Accurate apposition of the fractured surfaces must be combined with correction of any angulation or rotatory displacement, and adequate internal fixation must be secured.

An operation involving open reduction and grafting of two separate bones is quite a formidable undertaking and should not be employed if a simpler, but equally effective, procedure is available Simpler procedures are not usually equally effective, however, and are only indicated in selected cases

In recent fractures it is sometimes possible to limit operation to one forearm bone When one fracture has been exposed reduction of both fractures is secured by manipulation and internal fixation of the exposed fracture is sufficient to prevent re-displacement at either (Fig 93). The use of this technique should be limited to transverse fractures, which tend to be fairly stable once end-to-end apposition has been secured, and radiographs must be taken during operation to ensure that reduction of the unexposed fracture is adequate

Occasionally delayed union or non-union may occur at one fracture only In these circumstances, provided reduction is adequate, it is only necessary to expose and graft the fracture which has failed to unite

Operation may be carried out in two stages, each bone being dealt with separately at an interval of three or four weeks. Besides entailing two separate operations this technique has several disadvantages It is difficult to combine adequate skin preparation with effective immobilisation of the fracture which has already been grafted In old injuries it may be impossible to secure ade-

quate reduction unless both fractures are exposed and reduced simultaneously

In the majority of these injuries the most satisfactory procedure when operation is necessary is to expose, reduce and graft both fractures at a single operation

It is possible to use one dorsal incision through which both fractures can be exposed by mobilisation and retraction of muscles, but little time is saved by this manœuvre exposure is more difficult, and communication between the fracture hæmatomata may lead to subsequent cross union

I have found it more satisfactory to use two skin incisions and expose each bone separately The radius is exposed in the usual way and the bone-ends are cleared of fibrous tissue The ulna is then exposed through a separate incision and when this fracture has been cleared both fractures are reduced simultaneously

The ulna is grafted using an onlay graft fixed on the posterior surface of the bone the incision is closed and the radial fracture is fixed with an onlay graft applied on the anterior surface of the bone (Figs 96 and 97)

This technique is comparatively simple and does not entail keeping a tourniquet on the arm for an unduly long period Accurate reduction and stable fixation are ensured subsequent bony union is rapid and the danger of cross union is reduced to a minimum

PRE-OPERATIVE TREATMENT

Fracture of both bones of the forearm is associated with considerable local reaction and any operative measures must be deferred until this has subsided

The usual instruction in finger and shoulder exercises and a preliminary period of active exercises in old fractures is necessary

TECHNIQUE OF OPERATION

A tourniquet is used and the forearm is covered with sterile stockinet

The elbow is extended and the arm is supported on a narrow table The radius is exposed subperiosteally by the technique already described and the bone-ends are cleared of fibrous tissue

The wound is covered with a swab soaked in saline, the elbow is flexed and the forearm is placed across the patient s chest The

ulna is fairly accessible in this position and is exposed in the usual way When the fracture has been exposed subperiosteally and the bone-ends cleared both fractures are reduced by manipulation. The ulna is held in position with bone forceps, particular attention being paid to the correction of any angulation or rotatory displacement. The graft bed is prepared on the posterior surface of the bone and a tibial graft, about three inches long and half-an-inch wide, is placed in position, held with bone clamps and fixed with four screws Bone fragments are packed around the fracture and the ulnar wound is closed

The elbow is again extended, the radial wound is uncovered, and the fragments of this bone are held in normal relationship while the graft bed is prepared on the anterior surface and a tibial graft is fixed in position with screws Bone fragments are packed around the graft and fracture and the wound is closed

The arm is immobilised in a well-padded plaster extending from the upper third of the humerus to the metacarpal heads.

POST-OPERATIVE TREATMENT

Provided an adequate amount of padding has been used pressure symptoms due to post-operative swelling do not often develop and it is rarely necessary to bi-valve the plaster

Finger exercises are continued immediately after operation and it is important to regain a full range of metacarpo-phalangeal and inter-phalangeal movement as soon as possible

Three weeks after operation the padded plaster is taken off, skin sutures are removed, and the arm is immobilised in an unpadded plaster extending from the upper third of the humerus to the metacarpal heads. Immobilisation is continued until both fractures have consolidated, this is to be expected in from fourteen to twenty weeks When union is complete the plaster is removed and active exercises of the arm are commenced

About six weeks' intensive treatment, preferably at a Rehabilitation Centre, is necessary to restore full muscle power, and subsequently exercises are continued until a full range of joint movement is regained

CHAPTER XII

FRACTURES OF THE CARPAL SCAPHOID

THE various types and conditions of fracture of the carpal scaphoid probably present more problems than any other single fracture and there is no one method of treatment which will produce uniformly good results in these injuries

It is accepted that the results of treatment of scaphoid fractures are not uniformly satisfactory It is equally true that poor results are as often due to the use of a method of treatment which is not indicated in the particular fracture to which it is applied as to the ineffective application of the correct method of treatment

Conservative treatment by immobilisation is by far the most effective measure in the vast majority of fractures but in some circumstances good results can be produced only by operation

One of several operative measures may be indicated excision of the scaphoid excision of one fragment of the scaphoid bone grafting of the fracture and arthrodesis of the wrist each have their place in treatment

DISABILITY IN FRACTURES OF THE SCAPHOID

Two factors are responsible for the disability associated with fractures of the carpal scaphoid

The presence of the fracture itself causes disability commencing immediately after injury and persisting until the fracture has united by bone

Arthritic changes occurring in the wrist and mid carpal joints and caused by the presence of the un united fracture constitute the second factor If immobilisation is established soon after the injury and continued until the fracture has united these changes do not occur Once arthritis is established however it tends to be progressive and is not affected by subsequent union of the fracture

THE PLACE OF BONE-GRAFTING IN TREATMENT

Bone grafting is a method of securing bony union and adequate grafting is followed by union in a high proportion of fractures

Since over ninety per cent. of recent fractures unite as a result of conservative treatment grafting is not indicated in such fractures unless a test period of adequate immobilisation indicates clearly that union is not going to occur as a result of immobilisation alone

In old fractures the problem is more difficult. A much smaller percentage of such fractures unite as a result of immobilisation; this percentage decreases in proportion to the time between injury and the establishment of treatment, and once sclerosis of the fracture surfaces has occurred union cannot be secured by conservative treatment.

The disability in old injuries is not necessarily due to the presence of an un-united fracture, however, but may be due to arthritic changes in the wrist and mid-carpal joints These changes are not, in the early stages, apparent on radiological examination and the percentage of fractures in which they are present increases in proportion to the time which has elapsed since injury

Once arthritic changes have developed they become the dominating factor in the production of disability, and in these circumstances it is quite wrong to attempt to secure union of the fracture by bone-grafting Even if grafting is successful disability is not relieved, nor is the progress of the arthritis necessarily arrested Moreover, operation at this stage may be followed by a "flare-up" and a marked increase in the arthritic changes, with deterioration in the function of the wrist

INDICATIONS FOR BONE-GRAFTING

1. Recent fractures which show no evidence of union after three months' effective immobilisation.—All recent fractures do not unite as a result of conservative treatment In fractures which have been *immobilised immediately* after injury radiological examination three or four weeks later often shows some absorption or decalcification in the region of the fracture line This usually fills in if immobilisation is continued, and union takes place, but in about five per cent of fractures this is not the case, and these changes persist or become more marked If such a fracture shows no evidence whatever of union after three months' effective immobilisation bone-grafting is indicated (Figs. 98 and 99).

2. Untreated fractures with changes in the bony structure of the scaphoid.—If a fracture is untreated changes develop in the scaphoid

Within a few weeks of injury the fracture line becomes more obvious and an apparent increase in the gap between the fragments occurs

Fig 98

Fig 99

Fig 98 —A fracture after four months of effective immobilisation begun within 48 hours of injury There is considerable absorption in the region of the fracture and union is undoubtedly delayed

Fig 99 —The fracture shown in Fig 98 fourteen weeks after grafting (Iliac graft)

Fig 100

Fig 101

Fig 102

Figs 100 and 101 — A seven months-old untreated fracture of the scaphoid Separation occurs between the fragments on adduction of wrist showing that no union is present

Fig 102 —The fracture shown in Figs. 100 and 101 six months after grafting (Tibial graft.)

Six weeks to three months after injury further decalcification produces the so called " cyst " formation around the fracture (Figs 100 101

and 102). Later patchy sclerosis in the region of the fract surfaces indicates the early stages of established non-union (Fig 1(About seventy per cent. of fractures in which there is "cys formation will unite if they are effectively immobilised for a s ficiently long period, this percentage falls as the changes beco more marked, and in only about forty per cent of fractures w early sclerosis can good results be obtained by conservat treatment

Bone-grafting produces good results in about seventy per cent

FIG 103

FIG 104

FIG 103 —A fourteen-months-old untreated fracture The early sclerosis in the region of the fracture line is the first stage of established non-union

FIG 104,—A four-years-old fracture of the scaphoid with established non-union The lipping of the styloid process of the radius indicates the presence of early arthritis

suitable fractures, and grafting, properly carried out, is the meth of treatment which offers the best prospects of good results untreated fractures with marked absorption or early sclerosis in tl region of the fracture line

3. In fractures with established non-union.—Once the fractu surfaces have become sealed off with a layer of avascular sclerot bone, grafting is the only measure which will produce union of tl fracture (Fig 104) It must be remembered, however, that no union usually requires a period of two to three years to becom established, and during this time arthritic changes have almo always developed It is only on rare occasions, therefore, tha

operation for established non union is not contra indicated by the presence of arthritis

CONTRA-INDICATIONS TO BONE-GRAFTING

1 **Arthritis of the wrist and mid-carpal joints** —Once arthritic changes have developed the presence of an un united fracture becomes of secondary importance, and to graft the fracture at this stage is to bolt the stable door after the horse has gone '

The radiological evidence of arthritis is definite new bone formation beginning in the region of the tip of the styloid process of the

Fig 105

Fig 106

A four-years-old un united fracture associated with gross arthritis.

radius and dorsal aspect of the scaphoid decrease in the joint space between the proximal half of the scaphoid and the radius and os magnum and a general blurring of the clear-out outline of the carpal bones (Figs 105 and 106)

The degeneration fibrosis and roughening of the articular cartilage of the lower end of the radius scaphoid os magnum and semilunar which constitutes the early stages of arthritis is not associated with any radiological abnormality however and a negative radiograph does not exclude the possibility of early arthritis

The clinical findings and particularly the history are of more importance Early arthritis is characterised by a story of an injury one or two years previously which was ignored or treated as a sprain subsequent slight weakness of the wrist with pain on lifting

heavy weights or forcing the extreme of passive movement, and two or three months' history of a marked increase in pain and disability. In some instances the exacerbation of symptoms has followed a second injury, often of a trivial character.

The increase in symptoms and disability indicates the onset of arthritis, possibly precipitated by a second injury. In these circumstances the results of grafting are disappointing and operation is often associated with a further increase in the arthritic changes, which become obvious on radiological examination a month or two later

FIG 107

FIG 108

A fracture of the scaphoid two weeks and six weeks after injury The relative sclerosis of proximal fragment, due to cutting off of its blood supply, is quite obvious

An un-united fracture of the scaphoid sooner or later produces changes in the adjacent joints These changes usually develop within two years of injury, and grafting is contra-indicated in fractures in which there is clinical or radiological evidence of arthritis

2. Avascular necrosis of the proximal fragment of the scaphoid.—Avascular bone necrosis of the proximal fragment occurs when all the nutrient vessels to the scaphoid enter the bone distal to the fracture (Figs 107 and 108) Avascular necrosis is associated with permanent degenerative changes in the articular cartilage of the proximal fragment, and for this reason early excision of the fragment is the only treatment which will prevent subsequent arthritis It is not correct to attempt to secure union of the fracture either by prolonged immobilisation or by grafting

3 A small proximal fragment —Fractures may occur so close to the proximal pole of the scaphoid that the proximal fragment consists of a mere flake of bone (Fig 109) It is useless to attempt to insert a graft into a fragment of this type, and early excision is a much more satisfactory procedure Unless the proximal fragment consists of at least a third of the scaphoid grafting is contra indicated

4. Displacement between the scaphoid fragments —Grafting by the closed technique is of no value in scaphoid fractures with marked

FIG 109 FIG 110 FIG 111

FIG 109 —An un united fracture of the scaphoid in which the proximal fragment is very small

FIGS 110 and 111 — A six weeks-old fracture of the scaphoid with marked displacement between the fragments.

displacement (Figs 110 and 111) Even if union is secured the persisting irregularity in the articular surfaces produces subsequent arthritis Grafting by the open technique may be combined with operative reduction of the fracture but this often entails so much stripping of the scaphoid that the blood supply to the proximal fragment is cut off and subsequent avascular necrosis and arthritis is inevitable

PRINCIPLES OF OPERATION

The problem of grafting a fracture of the carpal scaphoid is exactly analogous to that of nailing a fracture of the femoral neck. Two alternatives are available The scaphoid and fracture may be exposed and the graft inserted under direct vision or the graft may

be inserted under radiological control through a small skin incision without any exposure or " stripping " of the bone

The " open " method was first described by Murray in 1934 [1] The scaphoid is exposed through a postero-lateral incision, the fracture line is identified, and the fracture surfaces cleared of fibrous tissue

The tubercle of the scaphoid is exposed by retraction and a drill is introduced in this region and threaded across the fracture and into the proximal fragment, its position being controlled by inspection at the fracture The drill is withdrawn and a bone peg, cut from the tibia, is driven along its track so that it crosses the fracture line

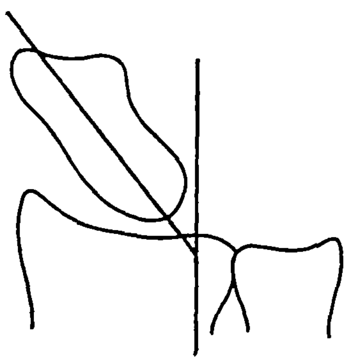

Fig 112

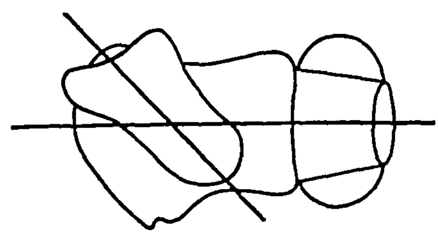

Fig 113

Diagrams showing the long axis of the scaphoid in relation to the long axis of the arm and transverse plane of the wrist

and immobilises the scaphoid fragments This technique entails opening the wrist joint and a considerable amount of stripping is necessary to obtain an adequate exposure This endangers the blood supply to the scaphoid and may produce avascular necrosis and subsequent arthritis

The " closed " technique, first described in 1941,[2] is based on the position of the scaphoid When the wrist is in neutral position the long axis of the scaphoid lies at an angle of 40 degrees to the long axis of the arm, and 45 degrees to the transverse plane of the wrist (Figs 112 and 113) If the forearm is rotated so that its transverse plane lies at an angle of 45 degrees to the horizontal, the hand being palm upwards and the wrist in neutral position, the long axis of the scaphoid lies in the vertical plane at an angle of 50 degrees to the perpendicular (Fig 114)

The forearm is held in this position in a special rest and a guide pin is introduced at the tubercle of the scaphoid and driven in in the line of the long axis of the bone This pin passes through the

centre of both fragments of the scaphoid and its position is checked by radiographs

The technique of radiography of the scaphoid is important, as the ordinary antero posterior and lateral views of the wrist are of no value in determining the position of the guide A true lateral view is obtained by centring over the scaphoid the hand being in neutral position and the forearm in 45 degrees supination In this view the kidney-shaped outline of the scaphoid is clearly seen (Figs 115 and 116) A true postero-anterior view is obtained by rotating the forearm through 90 degrees to a position of 45 degrees pronation and these views are used to determine the position of the guide pin

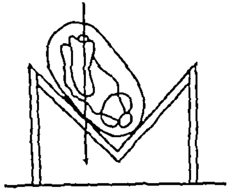

FIG 114

When the wrist is held in 45-degrees supination the long axis of the scaphoid is in the vertical plane

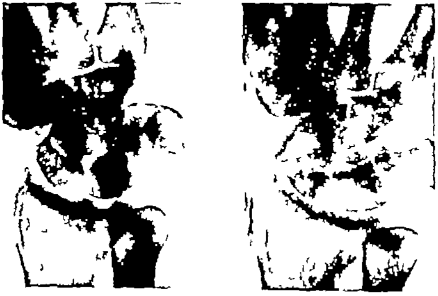

FIG 115 FIG 116

True lateral views of a normal (Fig 115) and a fractured (Fig 116) scaphoid.

If this is satisfactory a hollow-cutting trephine, 3/16th of an inch in diameter is threaded over the guide pin and is driven through the distal fragment, across the fracture and into the proximal fragment. The trephine is withdrawn, an autogenous bone peg is

inserted, driven home, and, after its position has been checked by radiographs, cut off flush with the tubercle of the scaphoid

This method does not entail any exposure or stripping of the scaphoid and, if attention is paid to the details of technique, it is possible to place a graft accurately in position with a minimum of disturbance of adjacent structures.

PRE-OPERATIVE TREATMENT

No pre-operative treatment other than the usual skin preparation is necessary.

TECHNIQUE OF OPERATION

1. "Open" technique.—A tourniquet is applied and the forearm is covered with stockinet. The skin incision begins over the postero-lateral aspect of the lower end of the radius and runs distally for about three inches, being slightly convex forwards The wrist is fully adducted to bring the posterior surface of the scaphoid clear of the tendons of the extensor carpi radialis longus and brevis muscles. These tendons are retracted medially, together with the tendon of the extensor pollicis longus, and the radial artery is mobilised and retracted outwards and forwards with the tendons of the abductor pollicis longus and extensor pollicis brevis, to expose the region of the tubercle of the scaphoid A transverse incision is made through the capsule of the wrist joint over the posterior surface of the scaphoid, and when this is opened up the fracture is exposed. The fracture surfaces are cleared of fibrous tissue, the fracture is reduced if necessary, and a quarter-inch drill is inserted in the region of the tubercle and driven across the fracture line into the proximal fragment The drill is withdrawn and a quarter-inch autogenous bone peg is driven home along its track. The incision is closed and the wrist immobilised in a padded plaster

2. "Closed" technique.—It is quite unnecessary to use a tourniquet for this operation The forearm and hand are covered with stockinet and placed in a rest, which supports the wrist, hand, and forearm horizontally, and rotated so that the transverse plane of the wrist lies at an angle of 45 degrees In this position the long axis of the scaphoid lies in the vertical plane at an angle of 50 degrees to the perpendicular (Fig 114)

A half-inch skin incision is made over the tubercle of the scaphoid, the subcutaneous veins are ligatured and the tubercle is exposed by

blunt dissection No attempt is made to clear the tubercle A 2 mm guide pin is inserted on the lateral aspect of the tubercle (Fig 117) and driven in in the line of the long axis of the scaphoid until it is felt to cross the fracture and enter the proximal fragment

The position of the guide pin is checked by radiographs (Figs 119 and 120) If necessary it is taken out and reinserted but if it is

Fig 117 Fig 118

Photographs taken at operation showing the insertion of the guide pin (Fig 117) and graft (Fig 118)

centrally placed in both fragments a hollow cutting trephine 3/16th of an inch in diameter is threaded over the guide pin and driven in to the proximal fragment (Figs 121 and 122) The trephine and guide are withdrawn and an autogenous bone peg is inserted and driven across the fracture line (Fig 118) The position of the peg is checked by radiographs if it is well home it is cut off flush with the tubercle of the scaphoid The wound is closed and the wrist is immobilised in a padded plaster

This technique is not particularly difficult, but requires close attention to detail The special rest, guide pins, and cutting

FIG 119

FIG 120

Postero-anterior and lateral views of the guide pin in position

FIG 121

FIG 122

Postero-anterior and lateral views of the guide pin and cutting trephine in position

trephine are essential The pin and trephine must be inserted with an electric drill and not by hand, and every stage of the procedure must be checked by radiographs

Various types of autogenous peg may be used Cortical pegs from the tibia are easily shaped and driven home, but bony union is probably quicker if iliac pegs are employed

POST-OPERATIVE TREATMENT

There is very little post operative reaction or pain and finger exercises can be started immediately. Ten days after operation an unpadded plaster is applied after the skin sutures have been removed. This plaster must prevent any movement at all at the wrist, and should extend from the metacarpal heads to the elbow and include the proximal phalanx of the thumb. Provided fixation is effective I do not believe that the position in which the wrist is immobilised is important.

Immobilisation must be continued until consolidation is complete; in most cases this occurs in from ten to twenty weeks, and in such fractures the subsequent function of the wrist is excellent. Occasionally immobilisation for a much longer period is necessary, however, and delay in union is usually associated with considerable deterioration in wrist function.

If fixation is ineffective, or if the plaster is discarded too soon, the peg does not become incorporated in the scaphoid and may even be gradually extruded. Extrusion is certain evidence that the peg is serving no useful purpose, and the incision should be reopened and the peg removed.

If grafting is followed by the development of arthritic changes in the region of the proximal half of the scaphoid immobilisation should not be continued for longer than four months, even if union has not occurred in this time. Arthrodesis should not be carried out, however, until after a trial period of some months' activity, as the function of such wrists is often much better than might be expected.

Bone grafting undoubtedly has a place in the treatment of fractures of the carpal scaphoid, but grafting is only indicated or necessary in less than five per cent. of such fractures. The results of grafting are, on the whole, satisfactory in selected cases, but the operation must not be regarded as an easy way of securing a good result in a difficult fracture, and should never be undertaken unnecessarily.

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CHAPTER XIII

FRACTURES OF THE METACARPALS AND PHALANGES

METACARPALS

IN fractures of the shafts of the metacarpals displacement is not usually very marked, union is rapid, and anatomically inadequate reduction does not prevent the recovery of full function of the hand For these reasons bone-grafting is not often necessary in the treatment of metacarpal fractures.

INDICATIONS FOR BONE-GRAFTING

1. After open reduction of transverse fractures of the metacarpal shafts.—Direct violence may produce transverse fractures of the

FIG 123

A nine-weeks-old fracture of the second metacarpal shaft which has not been accurately reduced and in which union has been delayed

shafts of the more exposed first, second, or fifth metacarpals with considerable displacement between the bone-ends, and in such

fractures non union is not uncommon Non union is directly due to inadequate reduction and unless this can be secured by manipulation open reduction and grafting of the fracture is indicated (Figs 123 124 and 125) These fractures should not be treated by continuous traction this method often fails to prevent non union and produces permanent limitation of finger movement

Fig 124

Fig 125

The fracture shown in Fig 123 eight weeks and six months after grafting An inlay graft with ball ends has been used.

2 **Multiple fractures of the metacarpal necks** —Occasionally fractures of the necks of either three or four metacarpals occur in association with considerable displacement of the metacarpal heads If this displacement cannot be controlled by any other method open reduction and grafting of the fractures may be necessary Operation on fractures of the metacarpal necks is often associated with permanent limitation of metacarpo-phalangeal movement and should be undertaken only in the presence of an uncontrollable displacement of the metacarpal heads of a degree sufficient to interfere seriously with the function of the hand

3. Established non-union of fractures of the metacarpal shafts.—Established non-union is most commonly seen in the transverse fractures already described Open reduction and grafting of the fracture is indicated (Fig. 126)

FIG 126
A fracture of the second metacarpal shaft with established non-union due to bone loss *Provided function of the index finger is good, grafting of this fracture is indicated*

FRACTURES IN WHICH GRAFTING IS NOT INDICATED

1. Oblique fractures of the metacarpal shafts.—In oblique fractures of the metacarpal shafts some overlap and shortening may occur This is limited by the splinting action of the adjacent metacarpals, and sufficient apposition of the fractured surfaces to ensure bony union can be secured by manipulation and immobilisation in plaster Provided bony union occurs shortening of the metacarpal does not seriously interfere with the subsequent function of the hand, and operation is not indicated in this type of fracture (Fig 127)

2. Isolated fractures of the neck of the fifth metacarpal.—The backward angulation which occurs at these fractures can be corrected by manipulation only if this is carried out soon after injury If such a fracture is first seen at a stage when the displacement cannot be corrected by manipulation the position should be accepted

and treatment concentrated on restoring a full range of finger movement (Fig 128) Open reduction and grafting of such fractures is followed by permanent limitation of metacarpo phalangeal movement

FIG 127

FIG 128

FIG 127 —A four-weeks-old fracture of the fifth metacarpal shaft with overlap and shortening This position should be accepted and is quite compatible with full function of the hand.

FIG 128 —Four-weeks-old fractures of the fourth and fifth metacarpal necks. The angulation which is present should be accepted and treatment aimed at restoring metacarpo-phalangeal movement

PRINCIPLES OF OPERATION

In transverse fractures of the metacarpal shafts reduction tends to be stable once it has been secured and the fracture can subsequently be protected almost completely by a well fitting plaster The graft is not therefore subjected to any very severe strains The onlay technique is not an entirely satisfactory method of grafting these fractures The graft increases the total diameter of the bone unduly and either presses against adjacent structures or projects beneath the skin in an unsightly way and the insertion of screws in a small bone is not desirable Inlay grafting is the neatest and most effective technique The graft bed is only 3/16ths of an inch wide and must be cut with care but quite adequate fixation can be secured, and subsequent union is rapid (Figs 124 and 125)

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The only effective method of dealing with fractures of the metacarpal necks is to employ an intramedullary graft The distal fragment is too short to allow fixation by any other technique, but its medullary cavity can be reamed out and the fragment fitted over a peg inserted in the medullary cavity of the shaft.

PRE-OPERATIVE TREATMENT

In recent fractures operation should be carried out as soon as the immediate effects of injury have subsided.

Active exercises of the fingers is the most important single factor in the treatment of these injuries Every digit should be exercised through a full range of movement for at least ten minutes of every hour throughout the day, and these exercises must be started as soon as possible after injury.

In old fractures associated with stiffness of the fingers a preliminary period of active exercises is necessary, and operation should not be undertaken until a reasonable and improving range of finger movement is present.

TECHNIQUE OF OPERATION

1. Fractures of metacarpal shafts.—A tourniquet is used. stockinet is applied in the usual way, and the hand is placed palm downward on a small table.

The affected metacarpal is exposed by a dorsal incision extending the whole length of the shaft, extensor tendons are retracted and the periosteum is incised in the line of the skin incision

The bone-ends are exposed subperiosteally, cleared of fibrous tissue, and the fracture is reduced Using a double saw, adjusted so that the outer surfaces of the blades are 3/16ths of an inch apart, a graft bed about one-and-a-half inches long is cut on the dorsal aspect of the bone A tibial graft, cut from the subcutaneous surface with a double saw adjusted so that the inner surfaces of the blades are just over 3/16ths of an inch apart, is inserted in the graft bed This graft should fit very closely and is tapped home with a punch until its cortical surface is flush with the cortex of the host bone.

If the graft and bed have been cut accurately the graft fits so closely that fixation is stable once it is in position, but as an added precaution it is fixed with two double loops of No 4 catgut which

are threaded around the metacarpal fragments with an aneurism needle

The periosteum and skin incision are sutured and the hand is immobilised in a lightly padded plaster extending from the meta carpal heads to the elbow An an added precaution the finger corresponding to the affected metacarpal is fixed in mid flexion

2 **Fractures of metacarpal necks** —Each fracture is exposed in a similar way through a skin incision over the dorsal aspect of the distal half of the metacarpal shaft The bone ends are cleared and when it is certain that reduction can be secured by manipulation the medullary cavity of the distal fragment and of the distal inch of the proximal fragment is reamed out A cortical peg from the tibia is driven into the proximal fragment so that it projects for between a quarter and half an inch The distal fragment is threaded over this projecting portion by manipulation and the fracture is impacted

The wounds are closed and the hand immobilised in a lightly padded plaster extending from the metacarpal heads to the elbow with the affected fingers fixed in 90 degrees flexion at the metacarpo-phalangeal joints

POST-OPERATIVE TREATMENT

Post-operative swelling is seldom sufficient to cause symptoms and exercises of the unimmobilised fingers are continued as soon as possible after grafting

Two weeks after operation an unpadded plaster is applied after the skin sutures have been removed This plaster is carefully moulded to the hand In a fracture of the metacarpal shaft it is unnecessary to continue immobilisation of the affected finger but in fractures of the metacarpal necks the metacarpo-phalangeal joints are fixed in 90 degrees flexion

Immobilisation in plaster is continued until the fracture has united Union is to be expected in from eight to twelve weeks

Fractures of the metacarpal shaft are not usually associated with any permanent disability a full range of finger movement is regained in plaster and the function of the hand is normal about a month after the plaster has been removed

The results of operation in fractures of the metacarpal necks tend to be disappointing however and some permanent limitation of metacarpo-phalangeal movement commonly occurs

PHALANGES

Bone-grafting is very seldom justifiable in fractures of the phalanges of the fingers, although occasionally it may be necessary in the proximal phalanx of the thumb.

INDICATIONS FOR BONE-GRAFTING

1. Fractures of the proximal phalanx of the thumb with established non-union.—A transverse fracture of the proximal phalanx of the

FIG. 129 FIG 130 FIG 131 FIG 132

FIGS 129 and 130 —A nine-months-old fracture of the proximal phalanx of the thumb with established non-union

FIGS 131 and 132 —The fracture shown in Figs. 129 and 130 immediately after grafting A small cortical graft, inserted through a drill hole, was used

thumb may fail to unite, usually because of the ineffective immobilisation An un-united fracture of this phalanx is associated with considerable disability and grafting is indicated (Figs. 129 and 130) Operation is often followed by considerable limitation of thumb movement, but this must be accepted. The function of a hand with a stiff thumb is immeasurably better than that of a hand in which the thumb has been amputated

FRACTURES IN WHICH BONE-GRAFTING IS NOT INDICATED

1. Fractures of the phalanges of the fingers.—The phalanges of the fingers form the posterior wall of the synovial-lined tunnel

through which the flexor tendons run and a fracture of the phalanx is always accompanied by injury to these tendons and their sheaths

Fractures which are allowed to unite in malposition or in which non union has become established are associated with organised adhesions between the tendons and their sheath and permanent limitation of finger movement Operation on the fracture is always accompanied by further adhesion formation and although union of the fracture in normal position may be secured the finger is stiff and useless

2 **Fractures of the distal phalanx of the thumb** —Non union of a fracture of the distal phalanx of the thumb is extremely uncommon Should it occur the distal fragment should be excised subperiosteally

PRINCIPLES OF OPERATION

The proximal phalanx of the thumb is too short and slender to allow preparation of an adequate bed for an onlay or inlay graft, and the use of an intramedullary peg is the only practicable method of grafting fractures of this bone (Figs 131 and 132)

PRE-OPERATIVE TREATMENT

No pre-operative treatment other than the usual skin preparation is necessary

TECHNIQUE OF OPERATION

A tourniquet is used and the hand is placed palm upward over a sandbag on a small table

The skin incision is made over the postero-lateral aspect of the phalanx and extends the whole length of the bone The phalanx is cut down on in the line of the skin incision and the fracture is exposed The bone-ends are cleared of fibrous tissue and sclerotic bone and the medullary cavity of each fragment is reamed out A cortical tibial peg is introduced into the longer fragment and the projecting end of this peg is threaded into the shorter fragment by manipulation The fracture is impacted and the incision closed

A well padded plaster is applied from the tip of the thumb to the elbow the thumb being in slight abduction and the interphalangeal joint in 80 degrees of flexion

POST-OPERATIVE TREATMENT

Finger exercises are practised from the first, and the padded plaster is changed two weeks after operation

Immobilisation in an unpadded plaster is continued until the fracture has united This is to be expected in from six to twelve weeks. When union is firm the plaster is removed and active exercises of the thumb are commenced

Some permanent limitation of thumb movement is not uncommon after this operation.

CHAPTER XIV

FRACTURES OF THE NECK OF THE FEMUR

PRIOR to the introduction of the stainless steel triflanged nail the results of treatment of adduction fractures of the femoral neck the "unsolved fracture," were almost universally bad In most cases the dictum born of despair, to "treat the patient and ignore the fracture" probably represented the best advice, but even if the patient's life was saved an un united fracture with permanent crippling was to be expected

The invention of stainless steel and the introduction by Smith Petersen in 1931 [1] of the triflanged nail altered the whole position Since then improvements in operative technique notably the introduction of the "closed" method of nailing have made it possible to ensure good results in about eighty per cent of these fractures

Many attempts have been made to improve further on these results and other methods of treatment, including bone grafting have been employed and advocated It must be remembered that while it is natural to seek the lost sheep and rejoice if it is found this course of action is unjustifiable if the safety of the rest of the flock is thereby endangered

PROBLEMS OF TREATMENT

While it is not difficult to reduce fractures of the femoral neck accurately by manipulation it is impossible to maintain adequate immobilisation by any form of external fixation

Operative treatment is necessary and the aim of the operation is to secure stable internal fixation, and produce the most favourable conditions possible for subsequent bony union and re-establishment of a normal blood supply to the femoral head

A well placed triflanged nail is the most effective known method of securing internal fixation and provided the "open" method of insertion which further jeopardises the already disturbed blood supply to the femoral head is avoided this stable fixation is in itself

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a potent factor in promoting bony union and restoration of a normal blood supply

There can be little doubt that it would be better to employ autogenous bone rather than a metallic foreign body if equally effective fixation could be secured This is not the case, the mechanical efficiency of a graft cannot be compared with that of a triflanged nail, and unless fixation is stable its osteogenic properties are of no account For this reason grafting cannot produce as generally satisfactory results as nailing in these fractures.

It is possible to combine grafting and nailing, and to some extent this technique has the advantage of both methods This procedure is considerably more difficult, both graft and nail must be perfectly placed, and it should be undertaken only when nailing alone is not sufficient

THE PLACE OF GRAFTING IN TREATMENT

Adduction fractures of the femoral neck can, from the point of view of treatment, be classified into three broad groups

1. Recent fractures.—Bone-grafting is not indicated in recent fractures (Fig 133), these injuries are best treated by nailing by the closed technique

2. Un-united fractures with a minimal amount of absorption of the femoral neck and a "live" femoral head.—If an unimpacted fracture of the femoral neck is not adequately reduced and immobilised union does not take place The femoral neck becomes absorbed in the region of the fracture line, and avascular necrosis of the femoral head may occur. The extent of these changes depends on the length of time the fracture has been allowed to remain inadequately immobilised, and on the degree of damage to the blood supply to the femoral head produced by the original injury If only limited absorption of the neck has occurred, and if the femoral head shows no evidence of avascular necrosis, the fracture should be treated by combined grafting and nailing (Fig 134)

3. Fractures with gross absorption of the femoral neck and/or avascular necrosis of the femoral head.—If gross absorption of the femoral neck has occurred (Fig 135), or if avascular necrosis of the femoral head has developed, neither bone-grafting nor nailing produces good results, and intertrochanteric osteotomy by the technique described by McMurray [2] is indicated

FIG 133 FIG 134

FIG 133 — A recent fracture of the femur This type of fracture is best treated by nailing

FIG 134 — A three-months-old fracture of the femoral neck. There is no gross absorption in the region of the fracture and no relative sclerosis of the femoral head. This type of fracture is suitable for combined nailing and grafting

FIG 135 FIG 136

FIG 135 — A fracture of the femoral neck which was nailed soon after injury The nail has been extruded and gross absorption of the neck has taken place At this stage grafting is not indicated

FIG 136 — A united fracture of the femoral neck which four months after injury was treated by combined nailing and grafting I prefer to introduce the graft a little more obliquely so that it lies parallel to the nail, and to drive it a little further into the femoral head

PRINCIPLES OF OPERATION

Inadequate immobilisation is the most important single cause of the delay or failure of bony union in fractures of the femoral neck. The only practicable method of securing operative fixation consists of driving a rigid internal splint through the centre of the femoral neck, across the fracture, and into the femoral head To be effective this splint must grip the soft cancellous bone of the neck and head very firmly.

The ideal splint should be mechanically effective and should not produce any reaction in the surrounding bone, and various types of nail, screws, multiple wires, and bone-grafts have been employed.

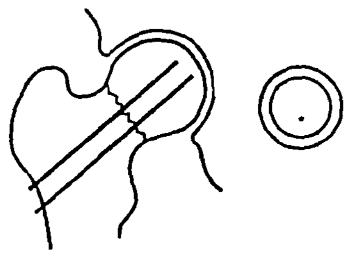

FIG 137
Diagram showing the correct position of the guide pins

It is impossible to embed an autogenous bone-graft sufficiently firmly to ensure the necessary fixation, a triflanged nail of vitallium or stainless steel is much more mechanically effective and does not usually produce any reaction. An autogenous graft is therefore most effective when used in combination with a triflanged nail (Fig. 136).

Two guide pins are introduced through the centre of the femoral neck, across the fracture, and into the femoral head, so that they lie one above the other and about half-an-inch apart These guide pins must be very accurately placed, they must not be too close to each other, neither must lie too near the outer surface of the femoral neck or articular surface of the hip joint, and both must penetrate well into the femoral head (Fig 137)

When the position of these pins has been checked by radiographs a cannulated triflanged nail is threaded over the lower and driven home. the graft bed is prepared with a cannulated drill or chisel introduced over the upper pin, and a graft either of iliac tibial, or fibular bone, is inserted and driven well into the femoral head.

PRE-OPERATIVE TREATMENT

Patients with this type of fracture are often elderly, and may be in poor general condition It is not justifiable to postpone operation indefinitely on this account particularly as fixation of the fracture is usually followed by a marked improvement in the patient's condition

No special pre-operative treatment, other than the usual skin preparation is necessary

TECHNIQUE OF OPERATION

The patient is transported to the theatre in bed and is anæsthetised before being placed on an orthopædic table of the Hawley or Watson Jones type It is an advantage to substitute a pelvic rest made of two layers of three-ply wood about half an inch apart for the usual metal rest The plate for antero-posterior radiographs can be quickly and easily inserted between these layers and need not be held in position by hand

The fracture is reduced by flexion of the hip through about 60 degrees firm traction in the line of the femoral shaft, and internal rotation of the leg When reduction appears to be complete the hip is extended internal rotation and traction being maintained and the foot is padded and fixed to the foot piece of the table with plaster The knee-rest is placed in position and the foot piece is fixed so that traction is maintained

Antero-posterior and lateral radiographs are taken, and when accurate reduction has been confirmed a four inch vertical incision is made over the outer aspect of the great trochanter and upper end of the femoral shaft The wound is screened with skin towels, the deep fascia and muscle are divided in the line of the skin incision and the bone is exposed by retraction

Using a quarter inch drill a hole is made through the cortex in the centre of the outer aspect of the shaft at the level of the lesser trochanter This hole lies one inch below the well marked transverse line indicating the upper level of the origin of the vastus lateralis and about three inches below the upper surface of the great trochanter

A 2 5 mm guide pin on a T handle is introduced through this hole and is driven up the femoral neck by hand With experience it is possible to introduce this guide accurately any approach to the cortical surface of the neck or head is indicated by an increased resistance and the guide can be felt to cross the fracture line and enter the femoral head

An indicator of the Engel May type is placed over the guide wire and antero posterior and lateral radiographs are taken On the antero-posterior view the guide should lie about the junction of the middle and lower thirds of the neck and head and should be

centrally placed on the lateral view. If it is not accurately placed a second guide is introduced through the appropriate cannula in the director, and further radiographs are taken

When the first guide is in position a second drill hole is made through the cortex and a second guide is introduced half-an-inch above and parallel to the first The position of the second guide is checked by radiographs and modified as necessary

When both guides are correctly placed (Fig 137) a triflanged nail is threaded over the lower and driven home The length of the nail is calculated by subtracting the length of the protruding portion from the total length of the guide, and the nail is introduced so that its lower flange lies in the line of the femoral shaft. The position of the nail is checked by radiographs, and the fracture is impacted

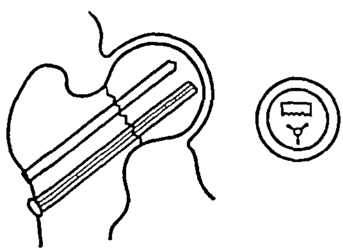

FIG 138
Diagram showing the nail and graft in position

A cannulated drill or osteotome is threaded over the upper guide and the graft bed is prepared I prefer to employ a cannulated osteotome half-an-inch wide The handle of the osteotome is angled, so that it is thrown clear of the guide, and the blade is calibrated

This osteotome is inserted transversely and is driven in to the required depth The osteotome is then withdrawn and a graft from the subcutaneous surface of the tibia, cut to the exact width of the blade with a double saw, is inserted and driven well into the femoral head The position of the graft is checked by radiographs, the protruding portion is cut off, and the fracture is again impacted (Fig 138)

The incision is sutured, a dressing is applied, and the patient is returned to bed No form of immobilisation other than a shoe with a transverse bar on the posterior aspect of the heel, or some similar device to prevent external rotation of the leg, is necessary.

This operation requires patience and attention to detail It is not necessarily unduly protracted, but its success depends on accurate placing of the graft and nail and the surgeon must be prepared to modify the position of the guide pins until they are placed absolutely correctly A series of radiographs are necessary and much delay is obviated if two X-ray sets are used These are placed to take an antero-posterior and a lateral view of the femoral neck at the beginning of the operation, and need not subsequently be moved.

POST-OPERATIVE TREATMENT

This operation does not cause much shock and is usually well tolerated even by old and enfeebled patients The freedom from pain which follows fixation of the fracture often produces a dramatic improvement in the patient's condition and outlook, and free movement in bed is encouraged from the first

Knee exercises are started a week after operation and hip exercises a fortnight later A month after operation the patient is allowed to sit up in a chair and a month later to commence getting about on crutches Weight bearing is not permitted until the fracture has consolidated completely

Union in this type of fracture is not to be expected in under four months and is unusual before six months Indeed consolidation may require a year to become complete If weight bearing is commenced before radiographs show that the fracture has united by bone fracture or extrusion of the triflanged nail is not infrequent

The results of this operation are in the main satisfactory Bony union occurs in about eighty per cent of fractures and although about fifty per cent. of patients subsequently develop some arthritic changes in the hip joint this is not necessarily associated with much disability It is advisable to remove the triflanged nail about a year after consolidation of the fracture is complete

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CHAPTER XV

FRACTURES OF THE SHAFT OF THE FEMUR

THE results of adequate conservative treatment of fractures of the shaft of the femur are good Accurate reduction, rapid union, and subsequent full function of the leg can be ensured in a high proportion of these injuries Such complications as shortening of the leg, distraction with delay or failure of bony union, refracture, or permanent stiffness of the knee joint are due to a misapplication rather than to a failure of conservative methods, and would not be prevented by wholesale adoption of operative reduction and internal fixation of all fractures of the femoral shaft Indeed, the post-operative management is more difficult than the ordinary conservative treatment of such fractures, and the complications which may arise after operation are much more serious than those associated with non-operative methods

Bone-grafting is a most valuable measure in certain types and conditions of these fractures, but should not be regarded as an alternative to conservative treatment and should never be employed when good results can be secured by simpler methods

INDICATIONS FOR BONE-GRAFTING

The age, sex, general condition, and occupation of the patient have a vital bearing on the decision as to the best method of treatment of any particular fracture of the femoral shaft Operation is almost never necessary in children and is seldom advisable for any condition short of established non-union in persons over sixty-five Each fracture is, to some extent, a separate problem, and any list of indications for operation can only be of a general nature

1. After open reduction of recent fractures.—In fractures of the femoral shaft it is not absolutely necessary to secure accurate apposition of the fracture surfaces and up to half-an-inch of overlap can be accepted provided the alignment of the upper and lower fragments is normal Reduction within these limits can usually be produced by skeletal traction and, if necessary, manipulation If, however,

an adequate reduction has not been secured within three weeks of injury open reduction and grafting is indicated

Transverse fractures in the upper third of the shaft are often particularly difficult to reduce [1] The short upper fragment is flexed and abducted and the upper end of the lower fragment is displaced upwards and inwards (Figs 139 140 and 141) Fractures at the

FIG 139

FIG 140

FIG 141

FIGS 139 and 140 —A fracture of the upper end of the femoral shaft after three months treatment on a well leg traction apparatus. Reduction is inadequate and union is delayed

FIG 141 —The fracture shown in Figs 139 and 140 after open reduction and grafting

junction of the middle and lower third of the shaft may also be difficult The upper end of the lower fragment becomes displaced backward and interposition of soft tissue may prevent reduction and accurate alignment of this fragment Interposition of soft tissue may also occur in other fractures of the femoral shaft, and causes inaccurate reduction and delay or failure of union unless corrected by operation

2 **For delayed union** —Although simple fractures of the femoral shaft usually unite readily several factors notably inadequate immobilisation or distraction may seriously delay union (Figs 142 143 144 145 146 and 147) Distraction, however slight always

Fig 142

Fig 143

Fig 144

Fig 145

Figs 142 and 143 —A four-months-old fracture of the femoral shaft Union is delayed, due to inadequate reduction Gross shortening has been allowed to occur

Figs 144 and 145 —The fracture shown in Figs 142 and 143 after the overlap has been corrected by *five days' strong skeletal traction*

Fig 146

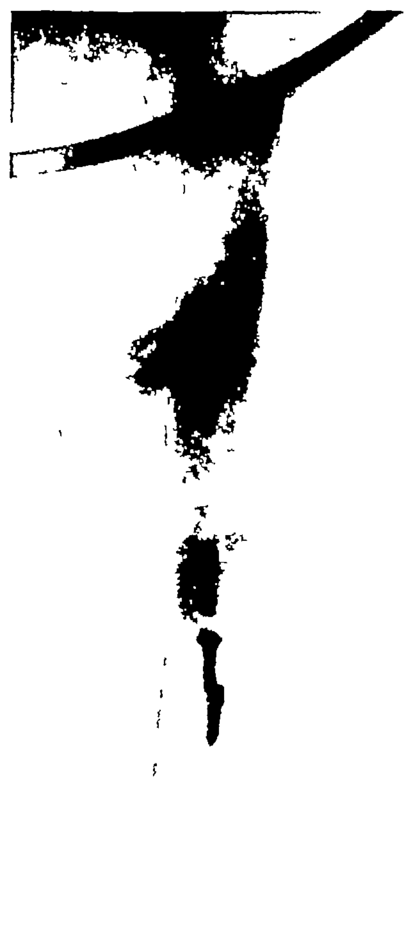

Fig 147

Figs 146 and 147 —The fracture shown in Figs 142–145 after open reduction and grafting Radiographs taken by portable set at conclusion of operation

delays union and if any material amount of distraction is allowed to persist for a few weeks union can only take place when the gap between the bone ends is bridged by new bone formation a process which may take between twelve and twenty four months In these circumstances the period of treatment necessary can be greatly reduced by timely bone grafting

3 **After refracture with re-displacement**—Refracture is probably commoner in the femoral shaft than in all other fractures and is

Fig 148

Fig 149

Fig 150

Fig 148—Refracture of four-months-old fracture of femur Probably due to lack of end to-end apposition with consequent shearing strain across newly formed callus.

Figs 149 and 150—The fracture shown in Fig 148 four months after open reduction and bone-grafting

usually due to too early cessation of immobilisation undue reliance on the extremely doubtful protective value of a walking caliper in adequate reduction—which results in a shearing strain being thrown on newly formed callus when weight bearing is commenced—dis traction or a combination of these factors After complete refracture with re-displacement (Fig 148) as distinct from simple bowing at the site of the fracture reduction is difficult and union often delayed and open reduction and bone grafting is the most generally satisfactory method of treatment (Figs 149 and 150)

4. After osteotomy.—A fracture of the femoral shaft may be allowed to unite in mal-alignment sufficient to cause material disability. Provided secondary changes in the hip or knee joint have not become established osteotomy and bone-grafting is indicated.

5. Established non-union.—Established non-union is indicated by sclerosis and "rounding-off" of the bone-ends and the development of a fibrous "false joint" at the site of the fracture. In such

FIG. 151

FIG 152

FIG. 151.—A nine-months-old fracture of the upper femoral shaft which has united by fibrous tissue only

FIG. 152.—The fracture shown in Fig 151 five months after open reduction and grafting

circumstances union can be secured only by operation, and bone-grafting is by far the most effective operative procedure (Figs 151 and 152).

PRINCIPLES OF . . . N

The three ess... al features ... bone-graft
fracture of the fe... haft a... tion of the
surfaces, restorati... mal ... agments.
internal fixation.

Reduction of t... c wi... mal al
much easier if co... ctio... ing

I have not found traction by means of an orthopædic table satisfactory for this operation The pulling force is transmitted from the foot piece of the table through the knee joint to the femur and if a full range of passive extension of the knee is not present, as is commonly the case in old fractures, the lower femoral fragment is tilted backwards and accurate reduction and alignment is made difficult Moreover the tension is fixed and not elastic, and requires constant adjustment during operation

It is much easier to operate with the leg in a Braun's splint and to employ skeletal traction by means of a pin through the lower end

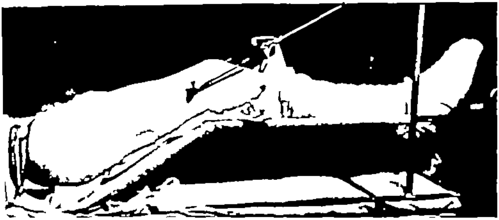

Fig 153

The leg in position ready for grafting Note the tourniquet in position and prevented from slipping down by the pin

of the femur inserted at the beginning of operation The amount of weight employed depends on the degree of overlap to be corrected, the traction force is in the line of the femoral shaft and of itself tends to produce normal alignment of the fracture (Fig 153)

This method of traction is not satisfactory for fractures of the upper third of the shaft in which the flexion of the upper fragment is too great to permit restoration of normal alignment by means of a Braun's splint In this type of fracture traction during operation is best maintained by a Roger Anderson well leg traction apparatus applied after the graft has been cut from the tibia

Fractures below the upper third of the shaft are best approached anteriorly as described by Henry * and can be exposed with a tourniquet in position A lateral approach is necessary for fractures of the upper third of the shaft a tourniquet cannot be used, and the operation is technically much more difficult

exposed, and a neurovascular bundle, consisting of the descending branch of the anterior circumflex artery and the nerve to the vastus lateralis, is clearly seen crossing the upper third of this muscle This bundle is mobilised and retracted upwards

The crureus and periosteum are divided by longitudinal incisions above and below the fracture, bone levers are slipped between the periosteum and the femur, and the fracture and femoral shaft are widely exposed by completing the division of the crureus The bone-ends are cleared of fibrous tissue and sclerosed bone and the

Fig 154

Grafting the shaft of the femur Using Henry's incision the fracture has been exposed and reduced, and the graft has been placed in position, held with clamps, and fixed with screws

fracture is reduced Reduction is greatly facilitated by the constant traction in the line of the femoral shaft, and it is not usually very difficult to secure end-to-end apposition and normal alignment

The femur is held with bone forceps while the graft bed is prepared on its anterior surface, the graft is placed in position, held with bone clamps, and fixed with six screws (Fig. 154). The periosteum and crureus are repaired with interrupted sutures, the wound is closed, and a pressure bandage is applied

Posterior and lateral plaster slabs are applied to the thigh, the tourniquet is removed, a Thomas splint with a bent-knee attachment is substituted for the Braun's splint, and the patient is returned to bed The traction should not be relaxed during this manœuvre The Thomas splint is slung in the usual way, and when this has been adjusted the traction can be decreased to ten pounds

2. **Fractures of the upper third of the shaft.**—A massive tibial

graft is cut from the uninjured leg the tibial incision is closed and a well leg traction apparatus is applied and adjusted so that strong traction is exerted on the fractured leg The patient is rolled towards his uninjured side the pelvis fractured leg and foot piece of the traction apparatus being supported on sandbags so that the lateral aspect of the fractured leg is easily accessible The pre-operative dressings are removed and the entire lateral aspect of the thigh is isolated with sterile towels

The skin incision begins immediately above the great trochanter and is carried down the centre of the lateral aspect of the trochanter and shaft to the lower third of the thigh Subcutaneous vessels are ligatured and the wound is isolated with skin towels

The deep fascia is incised along the whole length of the wound and this incision is carried through the muscle and periosteum down to bone over the great trochanter and upper fragment of the shaft and over the shaft well below the fracture The bone is exposed by retraction and working upwards and downwards from these incisions the vastus lateralis is completely divided until the lateral aspect of the fracture is exposed Considerable hæmorrhage from branches of the circumflex arteries is encountered as this muscle is divided in the region of the upper third of the shaft, and the use of a diathermy cautery to coagulate bleeding points considerably facilitates this stage of the operation

When the division of the muscle has been completed the periosteum is stripped from the femur to expose the lateral surface of the great trochanter and shaft above the fracture the region of the fracture and the lateral surface of the shaft well below the fracture Bone levers are slipped between the periosteum and femur and these are used as retractors to open up the incision

The bone ends are cleared of fibrous tissue and the fracture is reduced and held with bone clamps Abduction of the proximal fragment does not cause any difficulty when the well leg traction apparatus is used and when the fracture has been cleared it is usually possible to correct the flexion deformity of this fragment without much difficulty

The graft bed is prepared on the lateral aspect of the great trochanter and shaft with a chisel and the graft should extend from the top of the trochanter to well below the fracture The graft is placed in position held with bone clamps and fixed with screws

Screws one-and-a-half or two inches long should be used in the region of the great trochanter as these, unlike the screws in the shaft, have no second cortex on which to grip Bone chips are packed around the fracture, the periosteum and muscle are repaired with interrupted sutures, and the skin incision is closed A pressure bandage is applied and the patient is returned to bed in the well-leg traction apparatus.

This operation is often associated with considerable shock, and a certain amount of hæmorrhage is unavoidable Intravenous drip plasma should be started at the beginning of the operation and continued throughout, and the condition of the patient should be checked by periodic recording of the blood-pressure

In very old and enfeebled patients this operation can be performed in two stages The graft is cut, placed in a sterile container of normal saline or whole blood, the container is sealed and incubated at between 2 and 5 degrees centigrade The tibial wound is closed, a well-leg traction apparatus applied, and the patient returned to bed Ten days later the operation is completed, using the " stored " graft

POST-OPERATIVE TREATMENT

Post-operative shock is treated with morphia, intravenous plasma and, if considerable hæmorrhage has occurred during operation, blood transfusion

Quadriceps exercises are begun a week after operation and, in patients nursed in a Thomas splint with a bent-knee attachment, knee exercises a week later Every effort should be made to preserve full mobility of the patella, both by encouraging active exercises and by putting this bone through a full range of passive movement three or four times a day

The position of the fracture is checked by weekly radiographs, and it should be remembered that only light traction is necessary to stabilise the femur after adequate grafting

Six weeks after operation the traction is removed and the leg is immobilised in an unpadded hip spica Toe and quadriceps exercises are continued and weight-bearing in this spica is commenced ten weeks after operation

Immobilisation in a full-length spica is continued until consolidation of the fracture is complete This is to be expected between fifteen and twenty-five weeks after operation When union is sound the plaster is removed and the patient is instructed in ankle, knee,

and hip exercises These are carried out in bed for two or three weeks after removal of the plaster and at the end of this time if no untoward symptoms have developed graduated weight bearing is commenced

Exercises are continued and the patient is gradually returned to full activity A period of about two months' treatment at a Rehabilitation Centre is of the greatest value at this stage

The results of bone grafting of fractures of the femur are good in that it is possible to ensure firm union of the fracture and a useful limb Hip and ankle movement almost always return to normal but the degree of recovery of knee movement varies widely depending on the nature of the original injury the total period of treatment and the age of the patient

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CHAPTER XVI

FRACTURES OF THE TIBIA OR TIBIA AND FIBULA

FRACTURES of the shaft of the tibia are characterised by their liability to re-displacement after an initial adequate reduction, by a tendency to delayed union which, if unrecognised, leads to non-union, and by the severity of the permanent disability which follows union with angulation or a rotational displacement

There can be little doubt that the best results in the treatment of these injuries are obtained by the purely conservative measures of immediate reduction by manipulation and subsequent immobilisation in plaster Unfortunately, it is not always possible to secure accurate reduction by manipulation alone, nor is immobilisation in plaster sufficiently effective in fractures which are unstable or associated with œdema For these reasons the use of a distraction apparatus for reduction, transfixion pins incorporated in plaster, a combination of skeletal traction and immobilisation in plaster, and many other variations of conservative treatment are employed, and operative treatment is not infrequently necessary

Bone-grafting is a most valuable measure in certain types and conditions of tibial fractures

INDICATIONS FOR BONE-GRAFTING

1. Established non-union.—Once the fracture surfaces have become sealed off by a layer of avascular sclerotic bone operative treatment is necessary if union is to be secured (Figs 155 and 156) Bone-grafting is by far the most effective operative procedure in established non-union

2. Delayed union.—The rate of union of fractures of the tibia varies widely, not only with the age and general condition of the patient and the site and type of fracture, but also from individual to individual Several factors may, however, delay union far beyond normal limits Infection is always associated with delay The period of immobilisation necessary to permit union is, on an average,

FIG 155

FIG 156

A seven years-old fracture of the tibia, showing established non union.

FIG 157

FIG 158

FIG 159

FIG 160

FIGS 157 and 158 —A four months-old fracture of the tibia and fibula in which union has been delayed because of inadequate reduction

FIGS 159 and 160 —The fracture shown in Figs. 157 and 158 after open reduction and grafting

doubled if infection is present, and operation is usually contra-indicated in such fractures. Distraction (Figs 2, 3, and 4), repeated or late manipulations, inadequate reduction (Figs 157 and 158), or ineffective immobilisation are also associated with serious delay, and in such circumstances bone-grafting materially reduces the period of treatment necessary and obviates the danger of non-union becoming established (Figs 23 and 24, 159 and 160)

Fig 161 Fig 162 Fig 163 Fig 164

Figs 161 and 162 —A seventeen-months-old fracture of the tibia and fibula showing bone loss due to a too-sweeping initial debridement.

Figs 163 and 164 —A six-weeks-old fracture of the tibia and fibula which is not reduced At this stage manipulative reduction is difficult, and late manipulation is often followed by delay in union

3. **Bone loss.**—A wound from a high-velocity missile, a too-enthusiastic debridement of a compound fracture, or infection with subsequent sequestration may produce an actual loss of bone (Figs 161 and 162) Union can take place only when the defect is bridged by new bone formation, and if much bone has been lost union is, at best, seriously delayed, and may well be impossible unless the gap is bridged by an autogenous graft

Bone-grafting is indicated in such fractures, although a long preliminary period of treatment is usually required to allow all infection to subside, and it is often necessary to replace adherent scars by transferred skin flaps before undertaking grafting

4 **After osteotomy for mal-union.**—Normally the knee and ankle joints move in the same parallel axis consequently union of a tibial fracture in malposition either angular or rotational is associated with considerable disability This can be relieved by osteotomy at the site of the fracture and correction of the displacement and this should be undertaken provided the displacement is not of sufficiently long standing to have produced permanent changes in these joints

Osteotomy should always be combined with internal fixation and since osteotomy at the site of a recent fracture is often associated with subsequent delay in union fixation is best effected by means of an autogenous graft

5 **After open reduction.**—It is usually possible to reduce tibial fractures either by manipulation or by employing some form of distraction apparatus provided this is undertaken within two or three days of injury Occasionally even in recent fractures button holing of the periosteum or interposition of soft tissue prevents closed reduction (Figs 9 and 10) and this becomes in any type of fracture increasingly difficult in proportion to the time which has been allowed to elapse since injury In fractures more than a month old it may be impossible to secure reduction by conservative measures (Figs 163 and 164) Moreover late manipulation is associated with serious delay in union For these reasons many fractures at this stage are best treated by operative reduction This should always be combined with internal fixation and in fractures in which delay in union may be expected fixation is best secured by means of an autogenous graft (Figs 11 and 12 165–168)

6 **Unstable fractures.**—Some types of tibial fractures notably oblique fractures with a loose "butterfly" fragment are very unstable and cannot be controlled by any form of external fixation

Operative reduction and internal fixation is necessary and the use of an autogenous graft is one of the various methods of internal fixation which may be employed (Figs 169–172)

CONTRA INDICATIONS TO BONE-GRAFTING

1 **Infection.**—Since the tibia is subcutaneous a high percentage of fractures of this bone are compound Some degree of infection is not uncommon and union is consequently delayed On no account should bone grafting be undertaken in such fractures until all infection has subsided for at least three months

FIG 165

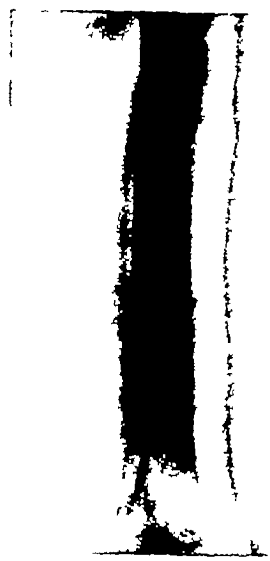

FIG 166

FIG 167

FIG 168

FIGS 165 and 166 —The fracture shown in Figs 163 and 164 after open reduction and grafting An onlay graft on the antero-medial surface was used

FIGS 167 and 168 —The fracture shown in Figs 163–166 six months after grafting, when the screws were removed.

FIG 169

FIG 170

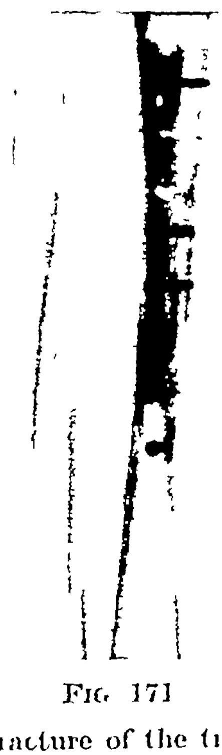

FIG 171

FIG 172

FIGS 169 and 170 —A four-weeks-old fracture of the tibia and fibula in which re-displacement in plaster has occurred after an accurate initial reduction This fracture was unstable because of comminution of the bone-ends

FIGS 171 and 172 —The fracture shown in Figs 169 and 170 after open reduction and grafting by the "split-bone" technique

2 **Adherent scars** —Wounds with skin loss associated with tibial fractures often produce avascular scars which are adherent to the underlying bone Before bone grafting such fractures scars should be completely excised and the defect filled by a transferred skin flap

PRINCIPLES OF OPERATION

Since the tibia is subcutaneous and easily accessible it might appear that bone-grafting a tibial fracture is a relatively simple procedure Such is not the case for while it is comparatively easy to expose the fracture and secure apposition of the fractured surfaces this is not enough Any angulation or rotational displacement between the upper and lower fragments will produce subsequent disability and these displacements are not easily avoided

The tibia as a whole is not straight but curved and the curve varies from individual to individual Moreover the only easily accessible surfaces the antero-medial and antero-lateral, are not only curved but twisted in the vertical plane All these factors must be considered in planning a sound grafting technique Various methods are employed, each with its advantages and disadvantages

Inlay grafting on the accessible antero medial surface is frequently practised but several difficulties arise with this technique

Sliding inlay grafts are particularly unsatisfactory The antero medial surface is most curved at the junction of the upper and middle and middle and lower thirds (Fig 178 A) and these points are common sites of fracture If a graft cut from the comparatively straight middle third is placed over such a fracture so that the cortex of graft and host coincide the curve of the graft is insufficient to restore normal alignment, and a varus deformity of the lower fragment with tilting of the inferior articular surface, is produced (Fig 178 B) This can be prevented only by counter-sinking one or other end of the graft into the medullary cavity (Fig 178 C and D) which is undesirable as it is difficult to assess or control the exact amount of counter-sinking necessary, and the introduction of the graft into the medullary cavity decreases the stability of the internal fixation and delays union

Providing both tibiæ are similarly curved a graft cut from an area on the sound tibia exactly corresponding to the graft bed will, when introduced so that cortex of graft and host coincide reproduce the normal alignment of the tibial fragments Such a graft must

be cut very accurately to fit the graft bed sufficiently closely to prevent its slipping into the medullary cavity of the host tibia

Onlay grafting is a simpler and more effective procedure. Such grafts should not, as a rule, be applied to the antero-medial surface (Figs 11 and 12, 165–168) The difficulties, already described, of making the curve of the graft coincide with the normal curve of the tibia arise Moreover, an onlay graft on the subcutaneous surface produces an unsightly prominence and may even make it difficult to

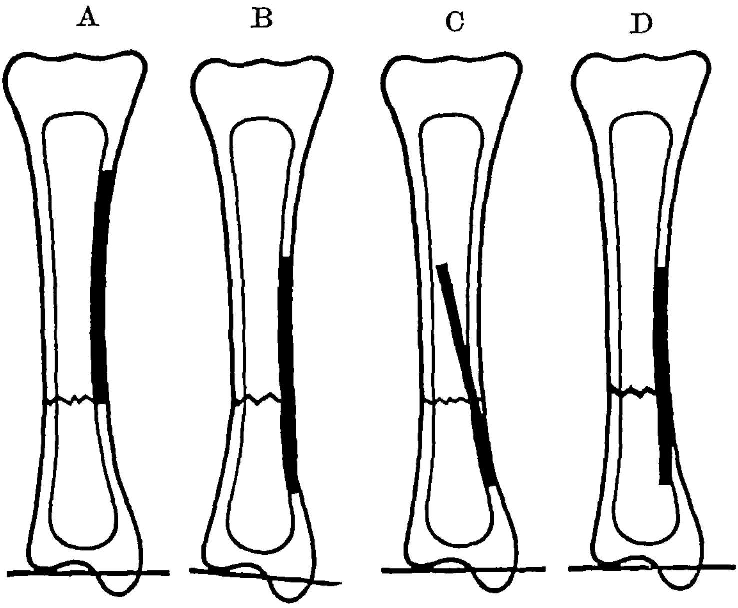

FIG 173

A The normal curve of the tibia B Mal-alignment produced by an accurately placed sliding graft C and D Normal alignment can be produced only by counter-sinking one or other end of the graft

close the skin without undue tension The graft is best applied to the antero-lateral surface, and care must be taken to cut the graft bed so that normal alignment is produced when the graft is in position (Figs. 159 and 160)

I have found the use of a massive "split-bone" graft a useful procedure in some circumstances[1] This is a variation of the split-bone technique described by Gill[2] in connection with the forearm bones The fracture is reduced and fixed with clamps or a small plate applied to the extreme posterior limit of the antero-medial surface The bone is then split in two in the plane of its posterior surface for about half its length, two-thirds of the split portion being on the longer and one-third on the shorter fragment The stout piece of bone from the longer fragment is slid across the fracture and fixed with four screws and the gap left is filled with the bone from the shorter fragment (Fig 174, A and B) The plate is removed and

radiographs are taken to ensure normal alignment Adjustments are easily made by removing the lowest screw, angling the lower fragment as much as may be necessary and replacing the screw

By this technique the fracture is bridged with a very massive graft any sclerosed bone around the fracture is widely opened up and the structure of the reconstructed bone approximates to normal (Figs 175 and 176) The method is however considerably more difficult than onlay grafting and entails a much wider subperiosteal exposure of the tibia

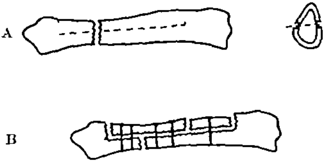

FIG 174

The split bone technique. The line in which the tibia is divided (A) and the reconstructed bone (B)

FIG 175

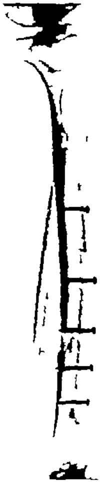

FIG 176

A tibia one year after grafting by the split bone technique *The structure of the bone has returned to normal.*

be cut very accurately to fit the graft bed sufficiently closely to prevent its slipping into the medullary cavity of the host tibia

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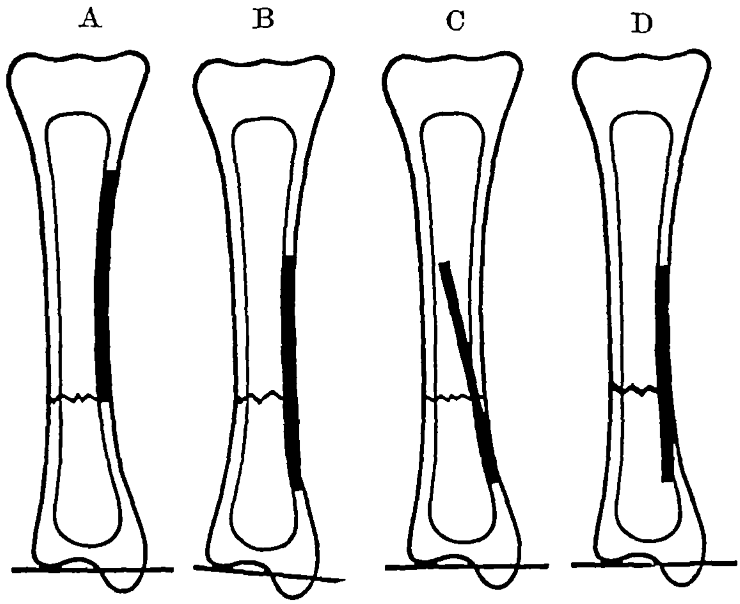

FIG 173

A The normal curve of the tibia B Mal-alignment produced by an accurately placed sliding graft C and D Normal alignment can be produced only by counter-sinking one or other end of the graft

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A

B

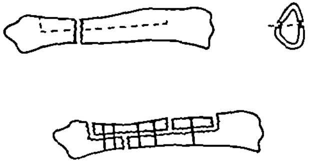

FIG 174
The split bone technique. The line in which the tibia is divided (A) and the reconstructed bone (B)

FIG 175

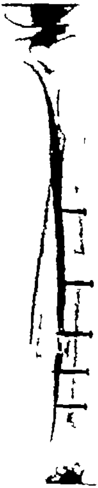

FIG 176

A tibia one year after grafting by the split bone technique
The structure of the bone has returned to normal.

be cut very accurately to fit the graft bed sufficiently closely to prevent its slipping into the medullary cavity of the host tibia

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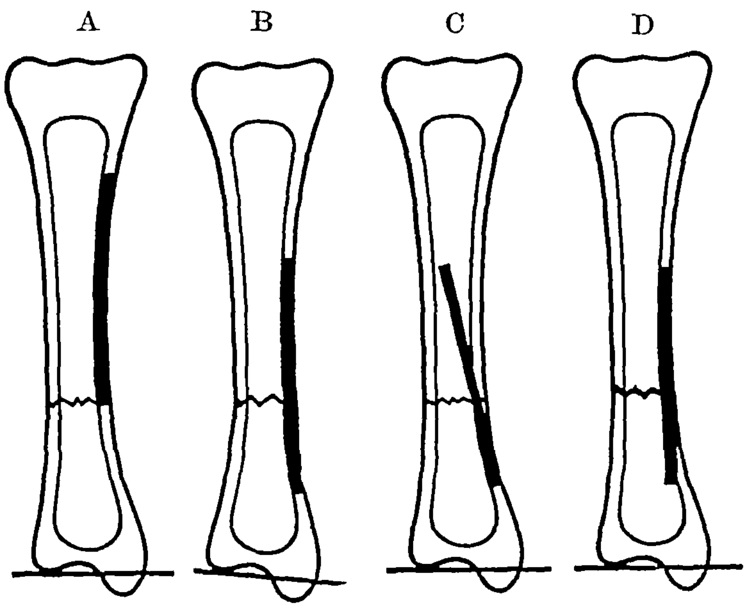

FIG 173

A The normal curve of the tibia B Mal-alignment produced by an accurately placed sliding graft C and D Normal alignment can be produced only by counter-sinking one or other end of the graft.

close the skin without undue tension The graft is best applied to the antero-lateral surface, and care must be taken to cut the graft bed so that normal alignment is produced when the graft is in position (Figs 159 and 160)

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D

E

F

ne" technique

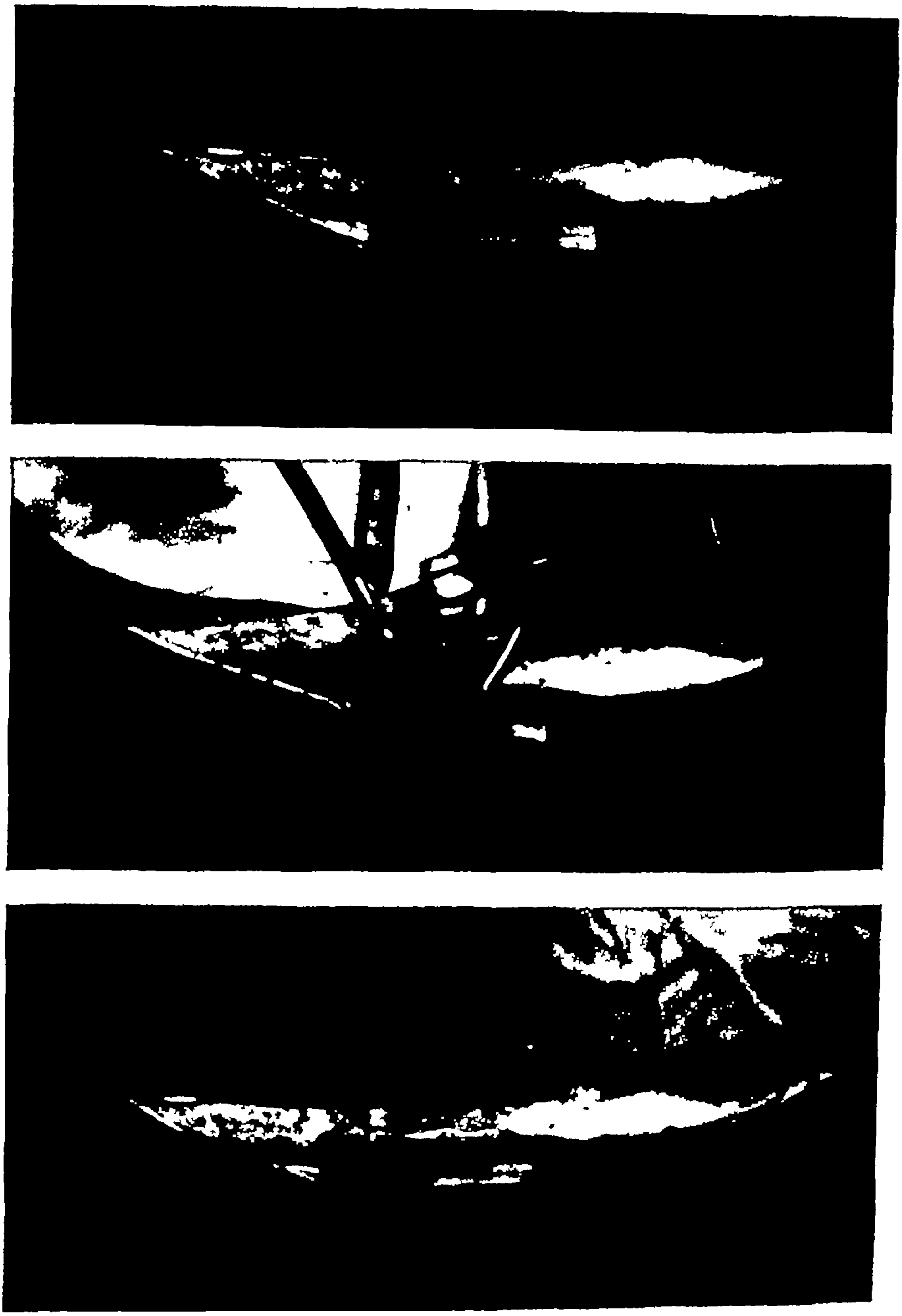
E. The anterior portion having been removed from the shorter fragment the anterior portion from the longer fragment is removed and placed across the fracture.

F The graft is fixed in position with screws and the plate is removed. When the position has been checked by radiographs the gap produced by the downward shift of the graft is filled with the anterior portion from the shorter fragment.

A

B

C



D

E

F

...e" technique

E. The anterior portion having been removed from the shorter fragment the anterior portion from the longer fragment is removed and placed across the fracture

F The graft is fixed in position with screws and the plate is removed. When the position has been checked by radiographs the gap produced by the downward shift of the graft is filled with the anterior portion from the shorter fragment.

PRE-OPERATIVE TREATMENT

In recent fractures operation should not be undertaken until the immediate effects of injury have subsided, although occasionally it may be justifiable to operate at once on fractures seen within an hour or so of injury and in which the skin is healthy and undamaged

Not uncommonly fractures of the tibia and fibula are associated with blistering of the skin and severe bruising and œdema of the leg, and two or three weeks' treatment in a posterior plaster slab with skin dressings is necessary before operation.

When shortening with overlap of more than half-an-inch has been present for longer than two weeks this should be corrected by skeletal traction before operation. A transfixion pin is inserted through the lower end of the tibia and with the leg on a Braun's splint, traction is maintained until shortening is corrected. A long posterior slab is then substituted for the Braun's splint the pin is removed, and the skin preparation is commenced as soon as the pin track has healed.

Before operation on a fracture which has been immobilised for many months the plaster should be removed and the leg immobilised in a short posterior plaster slab for two or three weeks During this period the patient practises toe foot, ankle, knee, and quadriceps exercises and the condition of the skin, usually thin and atrophic from immobilisation, and of the limb as a whole, improves rapidly.

TECHNIQUE OF OPERATION

1. Onlay grafts.—A tourniquet is applied and the leg is covered with sterile stockinet from the toes to just above the knee.

The skin incision is made over the antero-medial surface just behind the crest and extends about half the length of the tibia, its centre being opposite the fracture

The periosteum is incised in the line of the skin incision and is stripped from the tibia with an elevator. The bone should be completely exposed for about an inch immediately above and below the fracture, and the antero-medial and antero-lateral surfaces are exposed for the whole length of the incision It is not necessary when the onlay technique is employed to expose the posterior surface except in the immediate vicinity of the fracture.

The fractured surfaces are carefully cleared of all fibrous tissue, as little bone as possible being sacrificed during this process The

fracture is then reduced particular attention being paid to the alignment of the fragments and the avoidance of any rotational displacement If reduction is embarrassed by the presence of an intact fibula it is necessary to perform an osteotomy or to refracture this bone at the level of the tibial fracture

When the fracture is reduced the tibia is held with bone forceps while the graft bed is prepared on its antero-lateral surface A graft about five inches long and an inch wide, cut from the opposite tibia, is then placed in position and held with self retaining clamps The wound is covered with a sterile towel and antero-posterior and lateral radiographs are taken to check the alignment of the tibial fragments It is important to remember that these radiographs do not reveal a rotational displacement This must be avoided by observing the relationship between the foot and the knee joint Any mal alignment is corrected by angling the lower fragment as much as may be necessary and altering the shape of the graft bed with a chisel so that the graft lies snugly in the correct position When radiographs show that the reduction is satisfactory the graft is fixed to the tibia with four screws and the position is checked with further radiographs

Bone chips are then packed around the fracture and the periosteum is sutured It is not always possible to close the periosteum completely as the application of the graft considerably increases the total diameter of the tibia The skin is sutured and the leg is immobilised in a lightly padded plaster extending from the metatarsal heads to the upper third of the thigh

2 **"Split-bone" technique**—A tourniquet and stockinet are applied and the tibia is exposed through an incision placed over the posterior third of the subcutaneous surface and extending the whole length of the bone

The periosteum is incised in the same line and the tibial shaft is completely exposed subperiosteally Bone levers placed between the periosteum and the posterior surface of the bone and slid to the extremities of the wound act as retractors (Fig 177 A)

The fracture is reduced (Fig 177 B) and the tibia is fixed by a small plate applied to the extreme posterior edge of the subcutaneous surface (Fig 177 C) The position is checked by radiographs and any displacement is corrected by removing the screws which fix the plate to the lower fragment angling this fragment or bending

the plate as much as may be necessary, and reinserting the screws.

When the position is satisfactory the tibia is split in two in the plane of its posterior surface for about half its length (Fig 177, D) two-thirds of the split portion being on the longer and one-third on the shorter fragment This splitting is done with a single saw Using a blade of medium diameter the longitudinal cut is made first, and this cut is then deepened with a two-and-a-half-inch-diameter blade, which is sufficiently large to divide the opposite cortex When the end cuts have been made the detachment of the anterior halves of the split portions is completed with a chisel The piece of bone from the shorter fragment is removed first, the portion from the longer fragment is then removed (Fig 177, E), placed over the fracture and fixed in position with four screws (Fig 177, F) The gap left is filled with the shorter fragment, which is fixed with a single screw

The plate is removed, the position is again checked with radiographs, and if any medial or lateral bowing is present it is easily corrected by removing the lowest screw, angulating the lower fragment as much as may be necessary, and reinserting the screw

Bone chips are packed around the fracture, the periosteum and skin are closed and the leg is immobilised in a lightly padded plaster extending from the metatarsal heads to the upper third of the thigh.

POST-OPERATIVE TREATMENT

For two or three days after operation the patient is nursed with the leg raised and the foot of the bed on blocks Toe exercises are practised assiduously, and there is not usually any marked post-operative swelling or discomfort

Two or three weeks after operation the padded plaster is taken off the skin sutures are removed, and an unpadded plaster is applied from the toes to the groin Quadriceps and leg-raising exercises, which have hitherto been omitted because of the incomplete protection afforded by the padded plaster, are commenced, and are practised regularly

Four weeks after operation the patient is allowed to start getting about on crutches, and two weeks later direct weight-bearing in plaster is begun

Immobilisation in a full-length plaster is continued until the fracture has united This is to be expected in from twelve to eighteen

weeks When there is clinical and radiological evidence of consolidation the plaster is removed and quadriceps knee ankle and foot exercises are commenced the limb being supported in a firmly applied crepe bandage until all tendency to oedema has ceased

A period of between one and two months of intensive exercises is necessary before full function of the leg is restored and at this stage treatment is best carried out in an organised Rehabilitation Centre

The results of bone-grafting fractures of the tibia are usually most satisfactory firm and rapid union and full function of the leg are to be expected in a high proportion of patients

FRACTURES OF THE PATELLA

Bone grafting has no place in the treatment of fractures of the patella

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[2] Gill, A Bruce "Treatment of Un united Fractures of the Bones of the Forearm," *Surg Clin North America* 1 1933, 103

CHAPTER XVII

FRACTURES OF THE ANKLE

ALMOST all fractures in the region of the ankle can be reduced accurately by manipulation and subsequently controlled by immobilisation in plaster, and the results of treatment on these lines are good. Treatment by open reduction and internal fixation has not produced uniformly good results, nor has this method decreased the period of disability usually associated with these injuries. It is particularly undesirable to introduce metallic foreign bodies, in the form of plates or screws, around the ankle joint for the purposes of internal fixation.

In a small proportion of fractures reduction by manipulation is impossible, usually because of interposition of soft tissue, and in these circumstances open reduction is essential if non-union and dysfunction is to be avoided. Open reduction should be combined with internal fixation by means of autogenous bone pegs.

INDICATIONS FOR OPERATION

1. In fractures of the medial malleolus.—Fractures of the medial malleolus may be associated with displacement and complete separation of the malleolus from the tibia (Figs. 178 and 179). This may occur in either adduction or abduction-external rotation injuries and there may be associated fractures of the lower end of the fibula and posterior margin of the lower articular surface of the tibia. When such displacement occurs the periosteum over the malleolus is not necessarily torn in the line of the fracture, but may be avulsed from the malleolus so that a long fringe is left hanging from the tibia. This fringe tends to become folded between the fractured surfaces and prevents reduction by manipulation.

This interposition of soft tissue may occur in any type of fracture of the malleolus in which there is displacement, but is more common in abduction-rotation injuries, in which the fracture line tends to be transverse, than in adduction fractures, in which the fracture line is usually more vertical.

Fig 178

Fig 179

Fig 178 — A fracture of the medial malleolus with complete separation and displacement

Fig 179 —The fracture shown in Fig 178 after open reduction and fixation with an autogenous bone peg

Fig 180

Fig 181

Fig 182

Fig 180 —A fracture of the medial malleolus with interposition of soft tissue between the fracture surfaces.

Fig 181 —The fracture shown in Fig 180 after an attempt at manipulative reduction.

Fig 182.—The fracture shown in Figs. 180 and 181 eight weeks after open reduction and grafting

If accurate apposition of the fracture surface cannot be secured by manipulation the fracture should be exposed and the interposed tissue removed This fracture can then be reduced accurately and the internal malleolus is fixed in position with an autogenous bone peg (Figs. 180. 181. and 182).

Operation is indicated as soon as possible after injury. but quite often such fractures are first seen in the later stages when fibrous union is associated with pain and disability Bony union can be

FIG. 183

FIG. 184

FIG. 183 —A four-months-old un-united fracture of the lower end of the fibula

FIG. 184 —The fracture shown in Fig. 183 after grafting

secured by exposing and clearing the fracture surfaces, and pegging the malleolus in position.

2. Fractures of the lower end of the fibula.—Interposition of soft tissue is not common in fractures of the lower end of the fibula, but can occur particularly in transverse fractures associated with marked displacement If in such fractures accurate apposition of the fractured surfaces cannot be secured by manipulation the lower end of the fibula should be exposed, the bone-ends cleared, and the fracture fixed with an autogenous bone peg

In fibular fra ... terpo ... soft tissue commonly pr...
unrecognised u ... r ... ion renders exploration of
the fracture ne ... l

3 In posterior marginal fractures of the tibial articular surface — In fracture-dislocations of the ankle posterior displacement of the astragalus is associated with fracture of the posterior margin of the tibial articular surface The posterior marginal fragment is displaced backward and upward and this displacement is not always completely corrected when the dislocation is reduced by manipulation

It has been stated that correct replacement of the astragalus is the main consideration in treatment and that the position of the fragment is relatively unimportant the "step" formed at its junction with the main articular surface being of no significance as the fragment is displaced away from the joint [1] This is true in the majority of such injuries in which only a small proportion of the articular surface is carried on the posterior fragment Occasionally however the fragment includes more than a third of the articular surface and if any material upward displacement of such a large fragment is allowed to persist posterior subluxation of the astragalus occurs on plantar flexion of the ankle This is a source of permanent disability which is subsequently increased by the development of arthritic changes in the ankle joint

If a posterior marginal fragment carrying more than a quarter of the inferior articular surface of the tibia cannot be reduced by manipulation open reduction and fixation of the fragment by an autogenous bone peg is indicated (Figs 185 186 187 and 188)

FRACTURES IN WHICH BONE-GRAFTING IS NOT INDICATED

1 Oblique and spiral fractures of the lower end of the fibular shaft.—In abduction external rotation fractures of the ankle the lower end of the fibular shaft is fractured very obliquely Provided normal relationship between the tibia, the astragalus, and the malleoli can be restored by manipulation it is not necessary to secure accurate apposition of the fibular fractured surfaces (Fig 189) Indeed, stereoscopic radiographs show that some gap persists after manipulation in almost half these fractures This does not appear to interfere with adequate bony union and it is not necessary to continue immobilisation of the ankle until the gap has been completely obliterated a process which may take some months It is therefore unnecessary if reduction is adequate in other respects, to secure accurate apposition of the fracture surfaces by operation

2 In tibio-fibular diastasis.—Increasing attention has recently

FIG 191
A comminuted fracture of the medial malleolus Operative treatment of comminuted fractures is unsatisfactory

FIG 192
Avulsion of a small fragment from the medial malleolus.

spite of attempted manipulative reduction (Fig 192) In this type of injury the important factor is damage to the lateral ligaments of the ankle Healing of these ligaments follows effective immobilisation of the ankle and it is quite unjustifiable to attempt to secure accurate reposition of the avulsed fragment by operation

PRINCIPLES OF OPERATION

In recent fractures of the malleoli the interposed flap of periosteum can be seen and withdrawn when the fracture is exposed and after the fracture surfaces have been cleared of blood clot reduction is easily effected In old injuries the fracture surfaces are separated by fibrous tissue which must be removed completely by sharp dissection

When accurate apposition of the fracture has been secured a 3/16th inch drill is driven across and as nearly as possible at right angles to, the plane of fracture and an autogenous bone peg is driven along the drill track This peg is shaped to fit the drill hole very closely and is slightly tapered so that when it is driven home the fracture is impacted and firmly fixed (Figs 179 and 182)

An autogenous bone peg has several advantages over a metal screw as an agent for fixation Autogenous bone produces no reaction and even a hard cortical peg has some osteogenic value consequently union of the fracture is accelerated rather than retarded by the introduction of the peg The soft cancellous bone in the region of these fractures is not very efficiently gripped by the threads of an ordinary screw and fixation by means of a tapered peg is more stable When an autogenous peg is used there is no possibility of subsequent complications due to the presence of a metallic foreign body in the region of the ankle joint

PRE-OPERATIVE TREATMENT

In recent fractures operation should be carried out as soon as possible after it has become obvious that accurate reduction cannot be secured by manipulation Skin preparation is started when the immediate effects of injury have subsided If there is gross swelling and bruising around the ankle with blistering of the skin immobilisation in plaster for a week or ten days is indicated prior to skin preparation when the reaction is less severe a pressure

bandage and a temporary back splint for three or four days is all that is necessary

No special pre-operative treatment, other than the usual skin preparation, is necessary in old injuries

TECHNIQUE OF OPERATION

1. Fractures of the internal malleolus.—A tourniquet is applied, the pre-operative dressings are removed and, when the skin has been painted with an antiseptic, sterile stockinet is applied from the toes to the knee

A small incision is made over the tibial crest in its middle third and a cortical bone peg is cut with a single saw: The incision is closed and the peg is held in a vice and shaped with a file, so that it is exactly 3/16ths of an inch in diameter at its point and increases slightly in thickness towards its base

A second incision about two-and-a-half inches long is made over the centre of the medial aspect of the internal malleolus and lower end of the tibia and extending half-an-inch below the tip of the malleolus The periosteum is divided in the line of the skin incision and is gently separated from the medial surface of the malleolus and tibia with a blunt elevator In recent fractures when the periosteal flaps have been mobilised a fringe can usually be withdrawn from between the fracture surfaces, which are then separated only by soft blood clot In old injuries it is necessary to remove a layer of fibrous tissue from the fracture surfaces by dissection with a sharp elevator or osteotome

When the fracture has been cleared reduction is effected In isolated fractures the malleolus is gripped with retinaculum forceps and drawn into position while the foot is dorsiflexed and the ankle adducted by an assistant If there is an associated dislocation of the astragalus and fractures of the lower end of the fibula or posterior tibial margin these are reduced by manipulation before reduction of the internal malleolus is attempted

When the fracture surfaces have been brought into close and accurate contact a 3/16-inch drill is driven through the malleolus, across the fracture, and well into the lower end of the tibia This should be introduced as nearly as possi ght angles to the fracture surfaces and is t inserted ctric drill The drill is withdrawn a peg is t o its track and

gently tapped home with a mallet and punch The slight taper in the peg causes it to grip the bone very firmly and impact the fracture When the peg is well home it is cut off flush with the malleolus

The periosteum and skin are closed with interrupted sutures and the ankle is immobilised in a lightly padded plaster extending from the metatarsal heads to the upper end of the tibia

2 Fractures of the lower end of the fibula —When a peg has been cut from the tibial crest the lower end of the fibula is exposed by a vertical incision extending upward from a point half an inch below its tip

The fracture is cleared and reduced so that the fracture surfaces are in close and intimate contact A 3 16 inch drill is introduced at the tip of the fibula and driven upwards through the distal fragment across the fracture and up the centre of the fibular shaft Care must be taken to avoid angulating the lower fragment of the fibula outward during this process such an angulation widens the tibio-fibular socket and causes instability of the ankle The drill is introduced in the line of the fibular shaft that is almost vertically upwards and if necessary its position is checked by radiographs

The drill is then withdrawn and the bone peg is driven home and cut off flush with the fibula (Fig 184) The wound is closed and the ankle is immobilised in a lightly padded plaster

3 Fractures of the posterior margin of the inferior articular surface of the tibia.—A tourniquet is applied and a peg is cut from the tibial crest in the usual way The patient is then turned face downward and an incision is made along the medial border of the tendo Achillis extending upwards for about five inches from the level of the internal malleolus

The tendo achilles is retracted laterally to expose the lower end of the tibia crossed obliquely from above downward and medialward by the flexor hallucis longus This muscle is mobilised and retracted inward to expose the posterior surface of the bone and the displaced fragment The posterior displacement of the astragalus is corrected by manipulation the ankle is dorsiflexed and the foot is held by an assistant with the anterior aspect of the lower end of the tibia resting on a sandbag The tibial fragment can then be replaced in its bed without much difficulty and is held in position with retinaculum forceps while a 3/16th inch drill is driven through it into the tibia This drill should be introduced slightly upwards as the peg is

most efficient mechanically when placed in this axis It is helpful to introduce a second smaller drill which is left in position while the 3/16th-inch drill is withdrawn and the peg inserted (Fig 186). When the peg has been driven home the second drill is removed, the fracture is impacted, and the peg is cut off flush with the tibia

The wound is closed and the ankle is immobilised in a lightly padded plaster from the metatarsal heads to the knee, the foot being firmly held by an assistant to control any tendency to posterior re-displacement of the astragalus while the plaster is being applied.

POST-OPERATIVE TREATMENT

Toe and knee exercises are begun immediately after operation and are continued throughout treatment.

Three weeks after operation the padded plaster is removed and an unpadded plaster is applied Patients can then begin getting about on crutches, and direct weight-bearing is started in simple fractures four weeks after operation and four weeks later in fracture-dislocations

Immobilisation in plaster is continued until the fracture has united This is to be expected in between eight and fourteen weeks When union is complete the plaster is discarded and ankle exercises and a graduated return to full activity are commenced, a firm crepe bandage being worn from the metatarsal heads to the knee until all tendency to swelling around the ankle has ceased

The results of operative treatment of these injuries are good, the gait and function of the ankle usually being normal about six weeks after the plaster has been removed

REFERENCE

1 Watson-Jones, R, *Fractures and other Bone and Joint Injuries*, pp 593–596 (2nd ed). Livingstone, Edinburgh, 1941

CHAPTER XVIII

FRACTURES OF THE TARSUS

IN certain types of comminuted fractures or fracture dislocations involving one or other of the tarsal joints there is irreparable damage to articular cartilage Subsequent arthritis of the affected joint with pain and disability is inevitable and treatment should include a primary arthrodesis of the disorganised joint The use of an autogenous bone graft may be an essential feature of the operative technique of an adequate and well planned arthrodesis

INDICATIONS FOR THE USE OF A BONE-GRAFT

1 **Fractures of the os calcis involving the posterior subastragaloid joint.**—In forty five per cent of all fractures of the os calcis the posterior subastragaloid joint alone is directly involved The fracture line crosses the joint surface and the articular cartilage is contused and comminuted The various methods of treatment by traction lateral compression and rotation produce at best an approximately accurate reduction and the joint surface is not restored to normal The articular surface of the os calcis remains irregular and the cartilage of both os calcis and astragalus is contused and crushed Subsequent arthritis is inevitable and is probably in a large measure responsible for the intractable disability so often associated with these injuries Immediate arthrodesis of the subastragaloid joint for this type of injury was advised by Wilson in 1933 [1] and this would appear to be the only logical method of treatment After removal of the articular cartilage the joint should be packed with bone chips and fixed with a stout bone-graft

2 **Comminuted fractures or fracture-dislocations of the tarsal scaphoid.**—In comminuted fractures or fracture dislocations of the tarsal scaphoid the articular cartilage of this bone is permanently damaged by a combination of direct injury and interference with the blood supply to the displaced fragments Although accurate reduction may be achieved by manipulation or by open operation the damaged cartilage is subsequently replaced by fibrous tissue and

arthritis of the astragalo-scaphoid and scapho-cuneiform joints occurs. The persistent pain and disability associated with this condition is in striking contrast with the results of treatment by immediate arthrodesis of the astragalo-scaphoid and scapho-cuneiform joints An adequate arthrodesis, which includes stabilisation of the excised joints by means of an autogenous graft, produces a painless, fully functional, and well-shaped foot

3. Comminuted fractures or fracture-dislocations of the cuneiforms.—The position in regard to comminuted fractures or fracture-dislocations is exactly analogous to that in similar injuries of the tarsal scaphoid The most effective treatment is immediate arthrodesis of the scapho-cuneiform and cuneiform-metatarsal joints

PRINCIPLES OF OPERATION

1. Fractures of the os calcis involving the posterior subastragaloid joint.—The posterior subastragaloid joint can be exposed through a

FIG 193

The posterior subastragaloid joint has been excised, packed with bone chips, and immobilised with a stout autogenous graft (Radiograph taken at conclusion of operation)

small incision and the articular cartilage removed from the os calcis and astragalus This produces a gap which must be filled with bone chips if arthrodesis is to be rapid and certain Some bone can be removed from the lateral surface of the os calcis and used for this

purpose but bone from this source is not very osteogenic nor is the amount available completely adequate Moreover, after operation

Fig 104

Fig 105

Figs 104 and 105 —Radiographs taken three months after arthrodesis of the posterior subastragaloid joint

on these lines the joint is unstable and it is difficult to control tilting of the os calcis and prevent recurrence of a valgus deformity of the

heel by immobilisation in plaster This instability also prevents early weight-bearing because of pain and the danger of re-displacement in plaster If excision of this joint is combined with internal fixation by means of a bone-graft driven through the neck of the astragalus, across the joint and fracture line and well into the tuberosity of the

FIG 196

FIG 197

FIGS 196 and 197—A comminuted fracture-dislocation of the first cuneiform

os calcis, these difficulties disappear The graft is cut from the tibia and at the same time an ample amount of cancellous bone can be removed and used to pack the excised joint (Fig 193) After operation by this technique weight-bearing can be started in two or three weeks and fusion of the joint is rapid and certain[2] (Figs 194 and 195)

2. Comminuted fractures or fracture-dislocations of the tarsal scaphoid or cuneiforms.—The essential features of an arthrodesis for these types of injury are complete removal of the articular cartilage

of the damaged joints and subsequent stable fixation of the excised joints in the optimum position The articular cartilage is removed so that the affected bones fit together in such a way that the normal longitudinal arch of the foot is preserved The joints are then stabilised by means of an autogenous graft which is driven into a

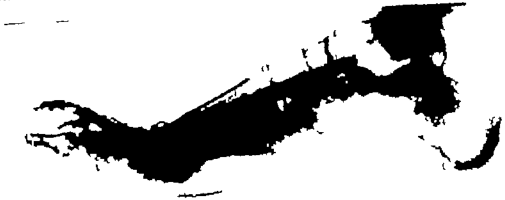

FIG 198

FIG 199

FIGS 198 and 199 —The fracture shown in Figs 196 and 197 three months after open reduction and arthrodesis. The graft was inserted from the medial surface being driven edgeways into a slot cut with a double saw

deep and narrow slot cut with a double saw A tibial graft is used and the method of introduction differs from the usual inlay tec in that the graft is introduced edgeways The slot which is the bed extends as far as possible into the bones on each side of excised joints, the graft is driven well home with a punch and protruding portion is smoothed down with a file (Figs 196 and 198 and 199)

PRE-OPERATIVE TREATMENT

These injuries are often associated with gross swelling and bruising of the foot and a period of treatment with pressure bandages and a back splint, or immobilisation in a temporary plaster, is necessary to allow these immediate effects to subside. The skin of the foot has a poor blood supply and wounds are notoriously liable to break down after operation. For this reason it is particularly essential that the skin should be healthy and skin preparation meticulously thorough before operation

The patient is instructed in toe exercises as soon as possible after injury and these must be practised assiduously.

TECHNIQUE OF OPERATION

1. Fractures of the os calcis involving the posterior sub-astragaloid joint.—A tourniquet is used and sterile stockinet is applied from the toes to the knee The posterior subastragaloid joint is exposed by a two-inch incision curving forward from the tip of the external malleolus. The peroneal tendons are mobilised, retracted downwards, and the joint capsule is divided in the line of the skin incision The joint is opened up by tilting the heel medialward, when surprisingly extensive damage to the articular cartilage of both os calcis and astragalus is usually observed Using a thin chisel, the cartilage is completely removed from both bones, together with sufficient bone from the medial half of the joint to correct any valgus deformity of the heel A second short incision is made over the anterior aspect of the neck of the astragalus, which is exposed by separating the tendons of the tibialis anterior and extensor hallucis longus. The limits of the tibial and scaphoid articular surface are defined and, while the foot is steadied by an assistant who holds the os calcis in normal relationship to the astragalus, two drill holes are made in the centre of the long axis of the neck with a 3/16th-inch drill which is directed towards the centre of the lower border of the tuberosity of the os calcis A chisel with a three-quarter-inch blade of uniform thickness is driven through the neck of the astragalus in the same line, joining the drill holes The chisel crosses the posterior subastragaloid joint, enters the os calcis, and is driven home until it approaches the limits of this bone. Its position is then checked by radiographs Two points are of importance during this

stage of the operation. The preliminary drill holes prevent splitting of the neck of the astragalus when inserting the chisel and the tibial and scaphoid articular surfaces are seen and avoided. Care is taken to prevent valgus tilting of the os calcis as the chisel is inserted.

An incision is made over the subcutaneous surface of the tibia and a graft the exact width of the chisel blade and about four and a half inches long is cut with a double saw. The loose cancellous bone is removed from the deep surface of the graft and is packed into the

FIG. 200

FIG. 201

FIGS. 200 and 201.—Axial views taken at operation showing the *chisel and graft in position*

posterior subastragaloid joint around the chisel blade. The graft is smoothed and shaped a little with a file so that it can be driven easily along the chisel track. The chisel is then freed by a few gentle taps with a mallet, withdrawn, and the graft is driven home along its track. After its position has been checked by radiographs (Figs. 21 and 22, 200 and 201) the protruding portion is cut off flush with the neck of the astragalus, the incisions are closed, and the leg is immobilised in a well padded plaster extending from the metatarsal heads to the knee.

2. Comminuted fractures or fracture-dislocations of the tarsal scaphoid or cuneiforms.—A tourniquet is applied and the limb is covered with sterile stockinet in the usual way. The skin incision extends from the centre of the neck of the astragalus to the centre of the dorsal aspect of the shaft of the first metatarsal. The tendons

of the extensor hallucis longus and extensor digitorum communis are mobilised and retracted lateralward. The incision is carried down to bone and the fracture or fracture-dislocation is exposed. Displaced fragments are reduced and the articular cartilage of the affected joints is excised. The joints excised are the astragalo-scaphoid and scapho-cuneiform in fractures or fracture-dislocations of the scaphoid, and scapho-cuneiform and cuneiform-metatarsal in fractures or fracture-dislocations of the cuneiforms Occasionally these injuries are combined, when all the joints on the medial side of the foot must be arthrodesed.

When the articular cartilage has been completely removed the foot is moulded into a normal shape and held by an assistant while a slot is cut on the dorsal aspect of the excised joints, using a double saw with the blades adjusted so that they are three-tenths of an inch apart This slot should extend well into the bone on each side of the joints to be arthrodesed.

The subcutaneous surface of the tibia is exposed and a graft, about three-quarters-of-an-inch wide and the same length as the graft bed, is cut with a single saw. This graft is inserted into the slot edgeways and is tapped home with a punch When it is well home the protruding portion is smoothed down with a file (Figs 198 and 199)

The incisions are closed and the foot is immobilised in a well-padded plaster extending from the metatarsal heads to the knee

POST-OPERATIVE TREATMENT

Post-operative swelling of the foot is not uncommon and pressure from inadequately padded plasters may produce permanent fibrotic changes in the muscles of the sole and prevent primary healing of the incisions by causing gangrene of the skin edges For this reason the plasters applied at operation should be padded with several layers of wool; if this is done it is seldom necessary to bi-valve the plaster on account of swelling

Toe exercises are begun immediately after operation and are carried out regularly by the patient

Three weeks after operation the padded plasters are taken off, the sutures are removed and unpadded plasters are applied. These plasters extend from the metatarsal heads to the knee and are moulded to the longitudinal and transverse arches of the foot.

Sorbo rubber heels are incorporated and weight bearing is commenced the patient being instructed so that he walks with a normal heel and toe gait

Immobilisation is continued until the arthrodesis is consolidated This is to be expected in between eight and sixteen weeks When the plaster has been removed the patient is instructed in ankle and foot exercises

Provided these joints are arthrodesed with the foot in a normal weight bearing position the results of these operations are good and a useful and painless foot is to be expected

REFERENCES

[1] Wilson, P D "Fractures and Dislocations of Tarsal Bones *South Med Journ* xxvi 833 1933.

[2] Armstrong J R., "Posterior Sub a tragaloid Arthrodesis in Fractured Os Calcis, *Lancet* 506, October 23, 1943

CHAPTER XIX

FRACTURES OF THE METATARSALS

IN fractures of the metatarsals displacement is not usually great, and bony union occurs rapidly Subsequent function depends on the shape of the foot as a whole rather than on the local condition at the site of the fracture Preservation of the longitudinal and transverse arches and avoidance of bony protrusions in the sole and clawing and limitation of movement of the toes are much more important than accurate apposition of the fractured surfaces For these reasons operative reduction and bone-grafting is seldom necessary in the treatment of metatarsal fractures.

INDICATIONS FOR BONE-GRAFTING

1. Displacement sufficient to cause subsequent disability which cannot be controlled by external fixation.—Occasionally the distal ends of the shafts or the necks of three or four adjacent metatarsals are fractured, and the heads and short distal fragments become displaced upward and laterally, while the distal ends of the proximal fragments project into the sole of the foot If these fractures are allowed to unite in malposition callus formation around the distal ends of the proximal fragments produces painful protuberances in the sole of the foot, while the displacement of the metatarsal heads causes clawing of the toes.

Such fractures can often be reduced and controlled by a combination of fixation of the foot in a well-moulded plaster and continuous elastic traction on the toes If, however difficulty is encountered in securing or maintaining reduction by these means open reduction and internal fixation by an autogenous bone-graft is indicated (Figs. 202. 203. and 204).

2. Fractures of the first or fifth metatarsal shafts with established non-union.—As a result of bone loss, interposition of soft tissue, or inadequate immobilisation a fracture of a metatarsal shaft may fail to unite. Two alternatives are then available, subperiosteal excision of the whole distal fragment, or bone-grafting of the fracture.

Fig 202

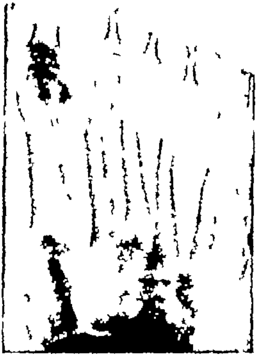

Fig 203

Fig 202 —Fractures of the second and third metacarpal necks with a dislocation of the fourth metacarpo-phalangeal joint after an attempt at manipulative reduction

Fig 203 —The fractures shown in Fig 202 after application of strong elastic traction to the toes. Reduction is still not accurate

Fig 204

The end result in the case shown in Figs 202 and 203 Both fractures are un united and the dislocation is unreduced. This type of injury is best treated by open reduction and internal fixation of the fractures

Excision of the distal fragment of the first or fifth metatarsal is contra-indicated and bone-grafting is necessary, but in un-united fractures of the second, third, or fourth metatarsals excision is probably the simplest and most effective procedure.

PRINCIPLES OF OPERATION

It is comparatively easy to expose, clear, and reduce fractures of the metatarsals, but it is often difficult to secure stable internal fixation by means of an autogenous bone-graft

In fractures of the distal ends of the shafts or necks of three or more metatarsals the short distal fragment can be held effectively only by means of an intramedullary peg It is not always necessary to fix each individual fracture, fixation of one may be sufficient to prevent re-displacement of any

In fractures of the first or fifth metatarsals with established non-union intramedullary pegs are less satisfactory than small inlay grafts inserted in the exposed medial or lateral surfaces of the bone.

PRE-OPERATIVE TREATMENT

In recent injuries operation is indicated as soon as possible after it has become obvious that the fractures cannot be controlled by external fixation When the immediate effects of injury have subsided skin preparation is started, particular attention being paid to the interdigital clefts, and operation carried out a few days later.

Toe exercises are an essential feature of treatment and no effort should be spared in encouraging the patient to persist assiduously with these exercises.

TECHNIQUE OF OPERATION

1. Multiple fractures with displacement.—A tourniquet is applied and the foot is covered with stockinet in the usual way

The fractures are exposed through separate incisions placed over the dorsal surface of the distal two-thirds of the affected bones. The extensor tendons are mobilised, retracted, and the fractures are exposed When the bone-ends have been cleared the fractures are reduced by manipulation and the tendency to re-displacement is assessed Oblique fractures are very unstable and re-displace immediately traction on the toes is relaxed, while transverse fractures

are comparatively stable once reduction has been effected If re-displacement occurs readily internal fixation of each individual fracture is necessary while in the more stable type it is necessary to fix only one or two of the fractures

An incision is made over the crest of the tibia and the required number of short cortical pegs are cut from this bone These pegs are inserted into the proximal fragments of the metatarsals to be immobilised, so that about a quarter-of an inch of the peg is left protruding The medullary cavity of the distal fragments is reamed out these fragments are "threaded" over the protruding portions of the pegs by manipulation and the fractures are impacted

The incisions are closed and the foot is immobilised in a well padded plaster extending from the metatarsal heads to the knee Particular attention is paid to moulding the plaster so that the longitudinal and transverse arches of the foot are supported

2 **Fractures of the first or fifth metatarsal shafts with established non-union.**—When a tourniquet and sterile stockinet have been applied the shaft of the affected metatarsal is exposed through a dorsal incision extending the whole length of the bone

The fracture is exposed subperiosteally and the bone ends are cleared of fibrous tissue The fracture is reduced and the graft bed is cut on the most accessible surface that is on the medial in the first and lateral in the fifth of the metatarsal This bed is cut with a double saw adjusted so that the blades are a quarter-of an inch apart, and should be about two inches long

The subcutaneous surface of the tibia is exposed and a graft two inches long and half an inch wide is cut with a single saw smoothed and inserted edgeways into the graft bed The graft is tapped well into the medullary cavity with a punch, the protruding portion is removed with nibbling forceps and smoothed with a file Cancellous bone is packed around the fracture and the skin incision is closed

The foot is immobilised in a well padded plaster extending from the metatarsal heads to the knee and moulded to the arches of the foot

POST-OPERATIVE TREATMENT

Toe exercises are recommenced immediately after operation and are practised by the patient for at least ten minutes of every hour throughout the day

The padded plaster is taken off in two weeks skin sutures are

removed, and a well-moulded unpadded plaster is applied. In multiple fractures a felt pad is placed in the sole under the heads of the second, third, and fourth metatarsals to support the transverse arch. Toe exercises are continued and four weeks after operation direct weight-bearing in plaster can be started

Immobilisation is continued until the fractures have united, the plaster being changed when necessary. Union is to be expected in from eight to ten weeks in recent fractures, and in from ten to sixteen weeks in fractures with established non-union.

When consolidation is complete the plaster is removed and the patient is instructed in foot exercises. These exercises should be carried out regularly, and a few weeks' treatment at an organised Rehabilitation Centre is of the greatest value at this stage.

The results of treatment of metatarsal fractures depend considerably on the age of the patient and on the condition of the foot prior to injury. In young adults with normal feet the results are satisfactory. In older patients and in those with some pre-existing foot deformity, particularly in those with a pes cavus or a clawing of the forefoot, some permanent limitation of toe movement, with pain of a metatarsalgic type after prolonged walking or standing, often occurs.

APPENDIX ONE

THE INCIDENCE OF BONE-GRAFTING IN THE TREATMENT OF FRACTURES

THE following figures represent the practice of a fracture clinic dealing for the most part with healthy adults between the ages of 18 and 50. This clinic served a small section of the community only, and consequently the area from which it drew patients was geographically much larger than is usual or desirable. For this reason a proportion of the less serious fractures were not sent the long distance necessary to attend the clinic, but were treated locally.

Fractures came to the clinic from two sources—either directly immediately after injury, or by transfer from other hospitals. These hospitals were not necessarily associated with an organised fracture clinic and in many instances a considerable period elapsed before transfer which was effected only when it became obvious that the results of treatment were likely to be unsatisfactory. Bone-grafting was necessary in a much higher proportion of this latter group than in those fractures seen immediately after injury.

No attempt has been made to differentiate between these two groups, as I feel that any specialised clinic must inevitably depend for part of its practice on problem fractures transferred for treatment some time after injury. Indeed, the treatment of such fractures is not the least important function of any fracture clinic.

The position in regard to fractures of the carpal scaphoid is rather different. The majority of these fractures which were grafted were sent from other fracture clinics under the same central control as the clinic from which these figures were drawn, because it was considered that grafting might be indicated. In effect, these fractures were drawn from a very much wider area, and accordingly they have been grouped together and not included in the general table.

The practice of this clinic was unusual in two other respects. A large number of the fractures treated were due to high velocity injuries, either aircraft accidents or gunshot wounds, and consequently

Fracture	Number Treated	Number Grafted	Per Cent	Indication for Grafting	
Phalanges (hand)	71	1 (Proximal of thumb)	1·4	Established non union	1
Femoral shaft	41	4	9·3	Refracture Malposition and delayed union Established non union	1 2 1
…a or tibia and fibula	90	13	14·4	Instability Malposition Malposition and delayed union Delayed union Bone loss Malunion Established non union	1 3 1 5 1 1 1
Fractures of ankle (Malleoli)	148	Int 5 Post 1 Ext 1	4·7	Malposition Malposition and delayed union	4 3
Os calcis	21	9 (Posterior sub-astragaloid arthrodesis)	42·9	Involvement of post. subast. joint	9
Tarsal scaphoid cuneiforms	20	2 (Arthrodesis)	10·0	Joint involvement	2

SCAPHOID FRACTURES OCCURRING WITHIN THE PRACTICE OF THE CLINIC

Number of Fractures Treated	Number of Fractures Grafted	Per Cent Grafted	Indications for Operation	
132	5	3·8	Grafted after a period of some months effective immobilisation failed to produce any evidence of union Grafted because of varying degrees of bony changes in the scaphoid Established non union	2 2 1

SCAPHOID FRACTURES TRANSFERRED FROM OTHER SPECIAL CLINICS

Number of Fractures Treated	Number of Fractures Grafted	Per Cent Grafted	Indications for Operation	
?	14	?	Grafted after a period of some months' effective immobilisation failed to produce any evidence of union	8
			Grafted because of varying degrees of bony changes in the scaphoid	4
			Established non-union	2

RELATION BETWEEN DELAY IN COMMENCING EFFECTIVE INITIAL TREATMENT AFTER INJURY AND INCIDENCE OF GRAFTING (CARPAL SCAPHOID FRACTURES)

Under 1 Week	1 Week–3 Months	3–6 Months	6 Months–1 Year	Over 1 Year
1	4	3	5	6

ARTHRODESIS NOT INCLUDED IN PREVIOUS TABLES

Joint Arthrodesed	Number
Wrist	3
Ankle	1
Elbow	1
M.-P. Hallux	1

APPENDIX TWO

THE RESULTS OF BONE-GRAFTING IN TERMS OF UNION BY BONE

THE primary purpose of a free bone graft is to assist in securing bony union of a fracture or bony ankylosis of a diseased or damaged joint. While it is true that union does not of itself necessarily produce normal function it is certain that function cannot be completely normal unless union by bone has occurred.

Before contemplating a bone grafting operation one must be able to assess the prospects of success. To some extent these prospects vary with each individual problem nevertheless it is possible to estimate the percentage union in various large series of published results.

It has been stated that at the present time bone grafting is in a state of flux. This statement can only be considered accurate if it is interpreted to mean that improvements and refinements of technique are constantly being devised as the result of experience in the vast amount of reparative surgery made necessary by war. If on the other hand it is implied that present methods are basically unsatisfactory such is not the case. The high percentage of success reported in large series of bone grafts compares favourably with the results of any major operation. For example in a series of 348 operations for massive bone defects only 13 failures are reported.[1]

I have analysed 100 consecutive cases of my own series of bone grafts and the results in terms of bony union are summarised in the following tables. The criterion of union was radiological evidence of consolidation of the fracture or bony ankylosis of the joint. It should be noted that in most instances the fracture or joint involved was mechanically stable as soon as the graft was fixed in position and that, judged by clinical standards union was sound long before consolidation was radiologically complete. It was our practice, however to continue protection of the fracture or joint in plaster until consolidation was complete and to encourage the patient with

the lesion thus protected, to engage in as vigorous activity as possible, rather than to cease immobilisation as soon as there was clinical evidence of union and to restrict activity until consolidation was complete.

In the 100 cases analysed no union was secured in two instances One fracture of the carpal scaphoid (Table III, 30) and one fracture of the tibia (Table IV, 46) failed to unite. Both these failures were due to post-operative infection.

In three of the 98 cases which did unite there was grave delay in union. In one fracture of the femur (Table IV, 40) consolidation was accepted as complete 19 weeks after operation and immobilisation was ceased. Two weeks later the femur and graft were refractured and a further period of immobilisation of 21 weeks (42 weeks in all) was necessary In two fractures of the tibia (Table IV, 41 and 48) post-operative infection occurred, part of the grafts sequestrated, and periods of immobilisation of 11 months and 27 months were necessary to secure union

These results can be summarised by saying that in two per cent of cases the operation failed in its object, the cause of failure being post-operative infection In a further three per cent of cases post-operative complications greatly delayed bony union, although this was ultimately secured

[1] Moore, John Royal, "Bridging of Bone Defects in Compound Wounds," *Journal of Bone and Joint Surgery*, xlii, 455, 1944

TABLE I

CLAVICLE, RADIUS, ULNA, RADIUS AND ULNA

	Type	Simple or Compound	Indication	Type of Graft	Post-operative Complications	Period of Immobilization	Union	Comments
	CLAVICLE							
1	Mid-shaft	Simple	Non union	Tibial onlay	None	12 weeks	By bone	
2	Mid-shaft	Simple	Malposition and delayed union	Tibial onlay	None	6 week	By bone	
3	Mid-shaft	Simple	Non union	Tibial onlay	None	13 week	By bone	
	HUMERUS							
4	Mid-shaft (comminuted)	Simple	Refracture	Tibial onlay	None	15 week	By bone	
5	Mid-shaft	Simple	Malposition	Tibial onlay	None	10 weeks	By bone	
6	Mid shaft	Compound	Delayed union	Tibial onlay	None	14 weeks	By bone	
	RADIUS							
7	Junction middle and lower third with inferior radio-ulnar dislocation	Simple	Malposition and instability	Tibial onlay	None	17 weeks	By bone	
8	Junction middle and lower third with R U dislocation	Simple	Malposition and instability	Tibial onlay	None	14 weeks	By bone	
9	Junction middle and lower third with R U dislocation	Simple	Malposition and instability	Tibial onlay	None	1[illegible] weeks	By bone	
10	Junction middle and lower third with R U dislocation	Simple	Malposition and instability	Tibial onlay	None	1[illegible] weeks	By bone	
11	Mid shaft (bone loss — G.S.W)	Compound	Bone loss	Tibial onlay	None	1[illegible] week	By bone	
	ULNA							
12	Mid shaft (comminuted G.S.W)	Compound	Delayed union	Tibial onlay	None	14 weeks	By bone	

TABLE I—*continued*

	Type	Simple or Compound	Indication	Type of Graft	Post-operative Complications	Period of Immobilisation	Union	Comments
	Ulna							
13	Junction middle and upper third of shaft with dislocation head of radius	Simple	Delayed union	Tibial onlay	None	16 weeks	By bone	
14	Upper third of shaft (comminuted G.S.W.)	Compound	Bone loss and delayed union	Tibial onlay	None	23 weeks	By bone	
15	Lower third of shaft	Simple	Malposition	Tibial onlay	None	12 weeks	By bone	
	Radius and Ulna							
16	Mid shafts	Compound	Non-union of both bones	Tibial onlays	None	16 weeks	By bone	
17	Mid shafts	Simple	Malposition of unstable fractures	Tibial onlay (radius only)	None	15 weeks	By bone	
18	Mid shafts	Simple	Malposition of unstable fractures	Tibial onlays	None	20 weeks	By bone	
19	Junction middle and upper thirds both bones	Simple	Malposition of unstable fractures	Tibial onlays	None	16 weeks	By bone	
20	Mid shafts	Simple	Malposition of unstable fractures	Tibial onlays	None	17 weeks	By bone	
21	Mid shafts	Simple	Delayed union and malposition	Tibial onlays	None	13 weeks	By bone	
	Other							
22	Proximal phalanx of thumb	Compound	Non-union	Tibial intramedullary peg	None	15 weeks	By bone	
23	Proximal phalanx of fifth finger	Simple	Fracture through cyst	Tibial intramedullary peg	None	10 weeks	By bone	

TABLE II

CARPAL SCAPHOID

	Nature	Indication for Operation	Type of Graft	Period of Immobilisation	Result	Comments
24	1[illegible] months, untreated	Absorption at fracture line	Iliac peg	10 weeks	Union by bone	Returned to full duty as cook
25	[illegible] months, untreated	Absorption at fracture line	Iliac peg	1[illegible] weeks	Union by bone	Returned to full general duties but some months later developed gradually increasing arthritis
26	3 months, untreated	Absorption at fracture line	Iliac peg	11 weeks	Union by bone	Returned to full duty as electrician
27	2 years, untreated	Non union	Iliac peg	14 weeks	Union by bone	Returned to full flying duty; slight disability which did not increase during next eighteen months
28	4 months, untreated	Absorption at fracture line	Iliac peg	1[illegible] weeks	Union by bone	Returned to full flying duty with no disability
29	13 months, untreated	Absorption at fracture line	Iliac peg	14 weeks	Union by bone	Returned to general duty but six months later developed increasing arthritis
30	8 months. Immobilised in plaster from outset	No union in spite of immobilisation	Iliac peg	17 weeks	No union	Developed subacute infection six weeks after operation; this resolved but there was no evidence of union and graft absorbed

TABLE III

SPINE

	Site	Indication for Operation	Type of Graft	Post operative Complications	Period of Immobilisation	Result	Comments
31	Body of 9th dorsal	Comminution	Double iliac	None	16 weeks	Fusion by bone	
32	Body of 9th dorsal	Comminution	Double iliac	None	16 weeks	Fusion by bone	
33	Body of 1st lumbar	Comminution	Double iliac	None	13 weeks	Fusion by bone	
34	Body of 1st lumbar	Comminution	Double iliac	None	15 weeks	Fusion by bone	
35	Body of 1st lumbar	Comminution	Double iliac	None	16 weeks	Fusion by bone	

TABLE IV

FEMUR, TIBIA AND FIBULA

	Type	Simple or Compound	Indication	Type of Graft	Post operative Complications	Period of Immobilisation	Union	Comments
	Femur							
36	Upper third shaft	Simple	Non union	Tibial onlay	None	21 weeks	By bone	
37	Mid shaft	Simple	Refracture	Tibial onlay	None	19 weeks	By bone	
38	Upper third shaft	Simple	Delayed union and malposition	Tibial onlay	None	25 weeks	By bone	
39	Mid shaft	Simple	Delayed union and malposition	Tibial onlay	None	16 weeks	By bone	
40	Mid shaft	Simple	Delayed union	Tibial onlay	Fracture of a graft in a fall 2 weeks after spica removed, 19 weeks after operation	42 weeks	By bone	Refracture and delay of union
	Tibia and Fibula							
41	Lower third shaft	Compound	Non union	Split-bone	Low - grade infection, sequestrectomy 7 months after grafting	11 months	By bone	Delay due to low-grade post-operative infection
42	Mid shaft (comminuted)	Simple	Malposition	Tibial onlay	None	15 weeks	By bone	

TABLE IV—*continued*

	Type	Simple or Compound	Indication	Type of Graft	Post-operative Complications	Period of Immobilization	Union	Comments
43	TIBIA AND FIBULA Mid-shaft	Simple	Malposition and delayed union	Tibial onlay	None	[illegible] weeks	By bone	
44	Double comminuted	Compound	Delayed union	Tibial onlay	None	21 weeks	By bone	
45	Mid-shaft	Simple	Malposition	Split bone	None	1[illegible] weeks	By bone	
46	Mid-shaft	Compound	Non-union	Tibial onlay	Flare of infection after operation; three sequestrectomies	Still in plaster [illegible] years after operation	Not united in [illegible] years	Infection
47	Mid-shaft	Compound	Delayed union	Tibial onlay and iliac chips	None	[illegible] weeks	By bone	
48	Mid-shaft	Compound	Non-union	Split bone	Flare of infection after operation; two sequestrectomies	2 months	By bone	Delay due to flare of infection after operation
49	Upper third shaft	Compound	Comminution and bone loss	Tibial onlay	None	[illegible] weeks	By bone	
50	Mid-shaft	Compound	Refracture	Iliac onlay	None	[illegible] weeks	By bone	

TABLE V

	Type	Simple or Compound	Indication	Type of Graft	Post-operative Complications	Period of Immobilisation	Union	Comments
51	Medial malleolus	Simple	Malposition	Tibial peg	None	8 weeks	By bone	
52	Medial malleolus	Simple	Malposition	Tibial peg	None	7 weeks	By bone	
53	Medial malleolus	Simple	Malposition	Tibial peg	None	8 weeks	By bone	
54	Medial malleolus	Compound	Non union	Tibial peg	None	11 weeks	By bone	
55	Medial malleolus	Simple	Malposition	Tibial peg	None	7 weeks	By bone	
56	Medial malleolus	Simple	Malposition	Tibial peg	None	11 weeks	By bone	
57	Medial malleolus	Simple	Malposition	Tibial peg	None	8 weeks	By bone	
58	Medial malleolus	Simple	Malposition	Tibial peg	None	9 weeks	By bone	
59	Medial malleolus	Simple	Malposition	Tibial peg	None	8 weeks	By bone	
60	Medial malleolus	Simple	Malposition	Tibial peg	None	8 weeks	By bone	
61	External malleolus	Simple	Malposition	Tibial peg	None	12 weeks	By bone	
62	Posterior malleolus	Simple	Malposition	Tibial peg	None	18 weeks	By bone	
63	Internal and external malleoli	Simple	Malposition and delayed union	Tibial pegs	None	12 weeks	By bone	
64	Proximal phalanx hallux	Compound	Non union	Tibial intra-medullary peg	None	11 weeks	By bone	

TABLE VI

OS CALCIS

	Type	Operation	Period of Immobilisation	Result	Comments
65	Fracture involving post subastragaloid joint	Excision joint & buried tibial graft	11 week	Bony fusion of joint and graft incorporated	
66	Fracture involving post subastragaloid joint	Excision joint & buried tibial graft	11 weeks	Bony fusion of joint and graft incorporated	
67	Fracture involving post subastragaloid joint	Excision joint & buried tibial graft	12 weeks	Bony fusion of joint and graft incorporated	
68	Fracture involving post subastragaloid joint	Excision joint & buried tibial graft	1[illegible] week	Bony fusion of joint and graft incorporated	
69	Fracture involving post subastragaloid joint	Excision joint & buried tibial graft	11 weeks	Bony fusion of joint and graft incorporated	
70	Fracture involving post subastragaloid joint	Excision joint & buried tibial graft	11 week	Bony fusion of joint and graft incorporated	
71	Fracture involving post subastragaloid joint.	Excision joint & buried tibial graft	10 weeks	Bony fusion of joint and graft incorporated	
	Fracture involving post subastragaloid joint.	Excision joint & buried tibial graft	1[illegible] weeks	Bony fusion of joint and graft incorporated	

TABLE VII

ARTHRODESIS OF WRIST

	Indication	Operation	Period of Immobilisation	Result	Comments
73	Unreduced trans-scapho-perilunar dislocation	Double bail-ended tibial graft	16 weeks	Graft completely incorporated	
74	Arthritis after fracture scaphoid	Double bail-ended tibial graft	16 weeks	Graft completely incorporated	
75	Very comminuted fracture lower end radius	Double bail-ended tibial graft	16 weeks	Graft completely incorporated	
76	Gunshot wound of carpus	Double bail-ended tibial graft	16 weeks	Graft completely incorporated	
77	Very comminuted fracture lower end radius	Double bail-ended tibial graft	16 weeks	Graft completely incorporated	
78	Very comminuted fracture lower end radius	Double bail-ended tibial graft	16 weeks	Graft completely incorporated	
79	Arthritis after fracture scaphoid	Double bail-ended tibial graft	16 weeks	Graft completely incorporated	
80	Arthritis after fracture scaphoid	Double bail ended tibial graft	16 weeks	Graft completely incorporated	
81	Arthritis after fracture scaphoid	Double bail-ended tibial graft	16 weeks	Graft completely incorporated	Graft fractured by violence three months later
82	Arthritis after fracture scaphoid	Double bail-ended tibial graft	16 weeks	Graft completely incorporated	
83	Arthritis after Keinbock's disease	Double bail ended tibial graft	16 weeks	Graft completely incorporated	
84	Arthritis after fracture scaphoid	Double bail ended tibial graft	16 weeks	Graft completely incorporated	Graft cracked by violence two months later
85	Arthritis after fracture scaphoid	Double bail ended tibial graft	16 weeks	Graft completely incorporated	

TABLE VIII

MID TARSAL ARTHRODESES

	Joints Fused	Indication	Operation	Period of Immobilization	Result	Comments
4	Scapho-cuneiform metatarsal	Arthritis following fracture-dislocation cuneiform	Joint excised tibial inlay graft	18 week	Joint fused and graft incorporated	
7	Scapho cuneiform metatarsal	Unreduced cuneiform metatarsal dislocation	Joint excised tibial inlay graft	14 week	Joints fused and graft incorporated	
8	Scapho-cuneiform metatarsal	Fracture dislocation first cuneiform	Joint excised tibial inlay graft	14 weeks	Joint fused and graft incorporated	
9	Astragalo scapho-cuneiform metatarsal	Fracture dislocation scaphoid and 1st and 2nd metatarsals	Joint excised tibial inlay graft	13 weeks	Joints fused and graft incorporated	
0	Astragalo scapho-cuneiform metatarsal	Arthritis following fractures scaphoid and first cuneiform	Joints excised tibial inlay graft	17 weeks	Joints fused and graft incorporated	

TABLE IX

OTHER ARTHRODESES

	Joint	Indication	Operation	Period of Immobilisation	Result
91	Ankle	Arthritis after fracture lower end tibia	Excision joint, inlaid tibial graft	21 weeks	Joint fused and graft incorporated
92	Ankle	Comminuted fracture lower end tibia	Joint excised, fibula used as onlay graft	14 weeks	Joint fused and graft incorporated
93	Ankle	Comminuted fracture lower end tibia	Joint excised, fibula used as onlay graft	19 weeks	Joint fused and graft incorporated
94	Ankle	Arthritis after fracture lower end tibia	Joint excised, fibula used as onlay graft	14 weeks	Joint fused and graft incorporated
95	Knee	Comminuted fracture upper end tibia (G S W)	Joint excised, X-tibial grafts	20 weeks	Joint fused and grafts incorporated
96	M-P Hallux	Hallux rigidus with arthritis	Joint excised, intramedullary tibial peg	18 weeks	Joint fused and graft incorporated
97	M-P Hallux	Hallux rigidus with arthritis	Joint excised, intramedullary tibial peg	16 weeks	Joint fused and graft incorporated
98	Elbow	G S W joint with gross bone loss	Humero - ulnar tibial graft	18 weeks	Graft firmly incorporated
99	Interphalangeal thumb	Arthritis after fracture into joint	Joint excised, intramedullary tibial peg	17 weeks	Joint fused and graft incorporated
100	Metacarpo phalangeal thumb	Arthritis after fracture dislocation	Joint excised, tibial inlay graft	15 weeks	Joint fused and graft incorporated

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